**Research Project Number:**
RES 2016-27

# FINAL REPORT

# HIGHWAY SAFETY MANUAL SAFETY PERFORMANCE FUNCTIONS & ROADWAY CALIBRATION FACTORS: INTERSECTIONS

## PHASE 2, PART 2

**Authored by:**

**Deo Chimba, PhD., PE., PTOE**
Department of Civil and Architectural Engineering
Tennessee State University
3500 John A. Merritt Blvd, Nashville, TN 37209
615-963-5430
dchimba@tnstate.edu

**Research Agency:**

Tennessee Department of Transportation

TN TDOT Department of Transportation

Submission Date:
June 30, 2020

# DISCLAIMER

This research was funded through the State Planning and Research (SPR) Program by the Tennessee Department of Transportation and the Federal Highway Administration under RES #: RES2016-27, Research Project Title: Highway Safety Manual, Safety Performance Functions (SPF) & Roadway Calibration Factors.

**Technical Report Documentation Page**

| 1. Report No.<br>RES 2016-27 | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| 4. Title and Subtitle<br>Highway Safety Manual Safety Performance Functions & Roadway Calibration Factors: Intersections | | 5. Report Date<br>June 2020 |
| | | 6. Performing Organization Code |
| 7. Author(s)<br>Deo Chimba, PhD., P.E., PTOE | | 8. Performing Organization Report No.<br>RES 2016-27 |
| 9. Performing Organization Name and Address<br>Department of Civil and Architectural Engineering<br>Tennessee State University<br>3500 John A. Merritt Blvd, Nashville, TN 37209<br>Email: dchimba@tnstate.edu<br>Phone: 615-963-5430 | | 10. Work Unit No. (TRAIS) |
| | | 11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address<br>Tennessee Department of Transportation<br>505 Deaderick Street, Suite 900<br>Nashville, TN 37243 | | 13. Type of Report and Period Covered |
| | | 14. Sponsoring Agency Code |
| 15. Supplementary Notes | | |

16. Abstract
To enhance safety, the Tennessee Department of Transportation (TDOT) is in the process of adopting the Highway Safety Manual (HSM) as a resource to facilitate decision making based on safety performance of its roadways. The predictive models which are known as Safety Performance Functions (SPFs) are used to forecast the expected crash frequency for various roadway facility types. The 2010 HSM recommends transportation agencies such as TDOT either to develop their own SPFs using local data or develop calibration factors for the HSM developed SPFs to reflect local conditions. This is because the HSM predictive models were developed using data from a subset of states. Geographical conditions in Tennessee may differ substantially from the factors used to develop the predictive models presented in the HSM such as terrain, weather, animal populations, driver populations, crash reporting thresholds, and crash reporting practices. Therefore, this study undertakes the task of developing 1) Tennessee-specific calibration factors, and 2) estimating Tennessee-specific fixed parameter and random parameter models. The accuracy of the models is determined by comparing their out-of-sample prediction performance. The calibration factors and models presented in this report are ready for implementation. Part 2 of the report focuses on rural multilane intersections and urban/suburban arterial intersections. Given the availability of relevant data in E-TRIMS, TDOT is in a good position to adopt HSM procedures and benefit from software applications that make it easier to use HSM procedures. AASHTO Safety Analyst tool is discussed in detail. An example demonstrates how the tool can use calibration factors and models to make predictions of crashes with and without countermeasures. At the end of the report, recommendations are provided for advancing safety analysis in Tennessee.

| 17. Key Words<br>Highway Safety Manual, Calibration Factor, Safety Analyst, Tennessee Department of Transportation | | 18. Distribution Statement<br>No restrictions. | |
|---|---|---|---|
| 19. Security Classif. (of this report)<br>Unclassified | 20. Security Classif. (of this page)<br>Unclassified | 21. No. of Pages 45 | 22. Price<br>N/A |

# Acknowledgement

The authors would like to thank the Tennessee Department of Transportation for supporting and funding this research. Special thanks are due to Mr. Jim Waters, Mr. Jeff Murphy, Mr. Zane Pannell, and Mr. David A. Duncan for their timely guidance in data collection efforts. The views expressed in this report are those of the authors, who are responsible for the facts and accuracy of the information presented herein. The results in this study do not necessarily reflect official policy and/or views of Tennessee Department of Transportation.

**NOTE**

This report for Phase II is divided into two parts based on analyses conducted for road segments and intersections. Part 1 presents in detail the analyses for rural multilane highways including both four-lane divided (4D) and four-lane undivided (4U), and three types of urban and suburban arterials which include two-lane (2U), four-lane divided (4D), and five-lane with two-way left-turn lane (2WLTL) (5T) road segments conducted by the University of Tennessee, Knoxville (UTK) team. Part 2 presents in detail the analyses for rural two-lane two way, rural multilane and urban and suburban intersections conducted by the Tennessee State University (TSU) team. To achieve project objectives, the teams have had close coordination during Phase II of the project.

# Executive Summary

This study developed calibration factors for intersections in Tennessee. These included three leg stop controlled intersections (3ST), four leg stop controlled intersections (4ST), three leg signalized intersections (3SG) and four leg signalized intersections (4SG). Three categories of intersections based on functional classes were considered including Rural Two-Lane, Two-Way Intersections, Rural Multilane Intersections and Urban Intersection (for single and multiple vehicle crashes). Utilizing five (5) calendar years of crash data from 2011 to 2015, and by applying crash modification factors (CMFs), corresponding statewide calibration factors for 2010 HSM Safety Performance Functions (SPFs) were developed as shown:

| | Calibration Factors (CFs) | | | |
|---|---|---|---|---|
| | Rural Two-Lane, Two-Way | Rural Multilane | Urban Intersection Single Vehicle Collisions | Urban Intersection Multiple Vehicle Collisions |
| Unsignalized three-leg (stop control on minor-road approaches) (3ST) | 0.633 | 2.201 | 1.805 | 2.505 |
| Unsignalized four-leg (stop control on minor-road approaches) (4ST) | 0.980 | 1.959* | 1.652 | 2.622 |
| Signalized three leg (3SG) | NA | NA | 0.819 | 2.000 |
| Signalized four-leg (4SG) | 0.730 | 0.526* | 0.982 | 1.834 |

*Without applying CMF

Further, the CFs were also developed for each of the four TDOT regions. Some intersection types were excluded due to an insufficient sample size. Those included rural multilane two-lane two-way four leg signalized intersections which did not have a sufficient sample size in regions 1, 2 and 4. Overall, the developed statewide calibration factors for rural two-lane two-way 3ST, 4ST and 4SG intersections are less than 1.0, indicating that statewide and regional intersections have fewer crashes than those predicted using the 2010 HSM SPFs. However, the calibration factors for rural multilane and urban/suburban intersections are greater than 1.0, indicating that these intersections have more crashes than predicted using the HSM 2010 SPFs.

Using Tennessee crash and traffic data, the study developed SPFs reflecting those developed in the HSM 2010. The sign and magnitude of the model constants and variable coefficients of the developed Tennessee SPFs are very close to those in the HSM 2010.

Rural Two-Lane, Two-Way Intersection:

$$N_{spf3ST} = exp\left[-9.25 + 0.71 \times ln\, ln\left(AADT_{maj}\right) + 0.41 \times ln(AADT_{min})\right]$$
$$N_{spf4ST} = exp\left[-7.01 + 0.44 \times ln\, ln\left(AADT_{maj}\right) + 0.53 \times ln(AADT_{min})\right]$$
$$N_{spf4S} = exp\left[-6.61 + 0.75 \times ln\, ln\left(AADT_{maj}\right) + 0.11 \times ln(AADT_{min})\right]$$

Other developed SPFs are as follows:

Tennessee SPFs Rural Multilane Intersections

$$N_{spf3ST} = exp\left[-3.985 + 0.359 \times ln\, ln\left(AADT_{maj}\right) + 0.175 \times ln(AADT_{min})\right]$$
$$N_{spf4ST} = exp\left[-6.222 + 0.042 \times ln\, ln\left(AADT_{maj}\right) + 0.904 \times ln(AADT_{min})\right]$$
$$N_{spf4SG} = exp\left[-8.641 + 0.837 \times ln\, ln\left(AADT_{maj}\right) + 0.300 \times ln(AADT_{min})\right]$$

Tennessee SPFs Urban Intersections for Single Vehicle Collision

$$N_{spf4SG} = exp\left[-5.39 + 0.17 \times ln\, ln\left(AADT_{maj}\right) + 0.31 \times ln(AADT_{min})\right]$$
$$N_{spf3SG} = exp\left[-5.97 + 0.36 \times ln\, ln\left(AADT_{maj}\right) + 0.14 \times ln(AADT_{min})\right]$$
$$N_{spf4ST} = exp\left[-3.16 + 0.11 \times ln\, ln\left(AADT_{maj}\right) + 0.08 \times ln(AADT_{min})\right]$$
$$N_{spf3ST} = exp\left[-3.95 + 0.10 \times ln\, ln\left(AADT_{maj}\right) + 0.17 \times ln(AADT_{min})\right]$$

Tennessee SPFs Urban Intersections for Multiple Vehicles Collision

$$N_{spf4SG} = exp\left[-7.38 + 0.58 \times ln\, ln\left(AADT_{maj}\right) + 0.43 \times ln(AADT_{min})\right]$$
$$N_{spf3S} = exp\left[-8.54 + 0.82 \times ln\, ln\left(AADT_{maj}\right) + 0.25 \times ln(AADT_{min})\right]$$
$$N_{spf4S} = exp\left[-5.36 + 0.25 \times ln\, ln\left(AADT_{maj}\right) + 0.54 \times ln(AADT_{min})\right]$$
$$N_{spf3ST} = exp\left[-4.84 + 0.13 \times ln\, ln\left(AADT_{maj}\right) + 0.52 \times ln(AADT_{min})\right]$$

TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

# 1. INTRODUCTION

## 1.1. Overview of Highway Safety Manual

The Highway Safety Manual (HSM) provides analytical tools and techniques for quantifying the potential effects on crashes as a result of decisions made in planning, design, operations, and maintenance [1]. According to the Federal Highway Administration, the capability of the state and local highway departments to incorporate explicit and quantitative consideration of safety into their planning and project development decision-making is immensely advanced by the HSM. One approach is the development of the Calibration Factor (CFs) taken in order to apply the HSM predictive models to the study area of interest. A Calibration Factor (CF) is a ratio of observed crashes to model-predicted crashes. The predicted crash frequency of an individual intersection is estimated using the SPF, applied crash modification factor (CMF), and calibration factors based on the intersection geometry configuration, traffic control features, and traffic volumes [2] [3]. A predictive model in the HSM or a Safety Performance Function (SPF) is used to estimate the predicted total crash frequency for a particular facility type, for a study year [1]. The general HSM crash prediction model is given as;

$$N_{Predicted(Adjusted)} = N_{SPF} \times (CMF_1 \times CMF_2 \times CMF_3 \ldots \times CMF_n) \times CF \quad (1.1)$$

where:

$N_{Predicted(Adjusted)}$: Adjusted total predicted crash frequency

$CMF_1, CMF_2, \ldots, CMF_n$: Crash Modification Factors

*CF*: Calibration Factor

$N_{SPF}$ : Average crash frequency under base condition used to estimate the crash frequency for the intersection, for a given base year, with specified base geometric conditions.

A base SPF for intersections is a function of AADT values on the major and minor roadways given as;

$$N_{spf} = exp\ exp\left[\alpha + \beta 1 \times ln\ ln\left(AADT_{maj}\right) + \beta 2 \times ln(AADT_{min})\right] \quad (1.2)$$

where $\alpha$, $\beta 1$ and $\beta 2$ are regression coefficients, $AADT_{maj}$ is the larger of the annual average daily traffic volumes of the two intersecting roads, and $AADT_{min}$ is the smaller of the two annual average daily traffic volumes. Table 1.1 to Table 1.4 shows the SPFs in HSM 2010.

**Table 1.1: SPFs for Rural Two-Lane, Two-Way Intersections in 2010 HSM**

| Intersection Type | SPF |
|---|---|
| Three-Leg Stop Controlled (3ST) | $N_{spf3ST} = exp\ [-9.86 + 0.79 \times ln\left(AADT_{maj}\right) + 0.49 \times ln\ (AADT_{min})\ ]$ |
| Four-Leg Stop Controlled (4ST) | $N_{spf4ST} = exp\ [-8.56 + 0.6 \times ln\left(AADT_{maj}\right) + 0.61 \times ln\ ln\ (AADT_{min})\ ]$ |
| Four Leg Signalized (4SG) | $N_{spf4SG} = exp\ [-5.13 + 0.6 \times ln\ (AADT_{maj}) + 0.2 \times ln\ (AADT_{min}]$ |

**Table 1.2: SPFs for Rural Multilane Intersections in 2010 HSM**

| Intersection Type | SPF |
|---|---|
| Three-Leg Stop Controlled (3ST) | $N_{spf3ST} = exp\ exp\left[-12.526 + 1.204 \times ln\left(AADT_{maj}\right) + 0.236 \times ln\ (AADT_{min})\ \right]$ |
| Four-Leg Stop Controlled (4ST) | $N_{spf4ST} = exp\ [-10.008 + 0.848 \times ln\left(AADT_{maj}\right) + 0.448 \times ln\ (AADT_{min})$ |
| Four Leg Signalized (4SG) | $N_{spf4SG} = exp\ [-7.182 + 0.722 \times ln\ (AADT_{maj}) + 0.337 \times ln\ (AADT_{min}]$ |

**Table 1.3: SPF at Urban Intersection for Multiple -Vehicle Collisions.**

| Intersection Type | SPF |
|---|---|
| Three-Leg Stop Controlled (3ST) | $Nspf = exp\ [-13.36 + 1.11 \times ln\ \left(AADT_{maj}\right) + 0.41\ ln\ (AADT_{min})\ ]$ |
| Three Leg Signalized (3SG) | $N_{spf=}exp\ [-12.13 + 1.11 \times ln\left(AADT_{maj}\right) + 0.26\ \ ln\ (AADT_{min})\ ]$ |
| Four-Leg Stop Controlled (4ST) | $N_{spf} = exp\ [-8.90 + 1.07 \times ln\left(AADT_{maj}\right) + 023 \times ln\ (AADT_{min})\ ]$ |
| Four Leg Signalized (4SG) | $N_{spf} = exp\ exp\ [-10.99 + 1.07 \times +0.23 \times ln\ (AADT_{min})\ ]$ |

**Table 1.4: SPF at Urban Intersection for Single -Vehicle Collisions.**

| Intersection Type | SPF |
|---|---|
| Three-Leg Stop Controlled (3ST) | $Nspf = exp\,[-6.81 + 0.61 \times ln\;(AADT_{maj})\; + 0.51\; ln\;(AADT_{min})\,]$ |
| Three Leg Signalized (3SG) | $N_{spf=} exp\,[-9.02 + .42 \times ln\,(AADT_{maj}) + 0\;.4\;\; ln\;(AADT_{min})\,]$ |
| Four-Leg Stop Controlled (4ST) | $N_{spf}\; = exp\,[-5.3 + 0.3 \times ln\,(AADT_{maj})\; + 0.12 \times ln\;(AADT_{min})\,]$ |
| Four Leg Signalized (4SG) | $N_{spf}\; = exp\,[-10.21 + 0.68 \times ln\,(AADT_{maj})\, 0.27 \times ln\;(AADT_{min})\,]$ |

The CMFs are used to address local or regional site conditions that are different from the base conditions, or to adjust any deviations of site characteristics from the base condition. When a CMF value is equal to 1.0, it means that the given countermeasure at the site has no impact on crash at that site. A CMF value less than 1.0 indicates that the countermeasure will reduce the expected number of crashes, and vice versa.

The CF is defined as a factor to adjust frequency estimates produced from a safety prediction procedure in order to approximate local conditions. The factor is computed by comparing observed crash data at the state, regional, or local level to estimate crashes obtained from predictive models [4]. The CF accounts for differences between the jurisdiction and time period for which the predictive models were developed and the jurisdiction and time period to which they are applied by HSM users [1]. When a computed CF is equal to 1.0 that means the predicted crashes are equal to observed crash frequency. When a computed CF is less than 1.0, it indicates that the observed crashes for the given facility type are less than the one predicted by base model, and vice versa. Calculation of calibration factor is as shown in equation (1.3);

$$CF = \frac{\sum_{all\ sites} N_{observed}}{\sum_{all\ sites} N_{predicted(unadjusted)}} \tag{1.3}$$

where;

$N_{Predicted\ (Unadjusted)}$: Unadjusted total predicted crash frequency, and

$N_{Observed}$ : Total number of observed crushes during the study period

## 1.2. HSM Calibration from Other States

Different states have calibrated HSM SPFs or have developed their own local SPF for their jurisdiction as described in the following section.

### 1.2.1. Utah HSM Calibration

The HSM calibration in Utah involved two lane highways. The scope of calibration involved 426 recorded crashes on 157 segments from rural Two-Lane, Two-Way roads [4]. The calibration involved three years of data from 2005 to 2007. Utah researchers developed their own jurisdiction-specific SPFs due to availability of data by employing the negative binomial regression and an over-dispersion parameter. They showed that the correlation between local characteristics and crash rates in Utah was improved by the jurisdiction specific model. They collected data as random as possible while including various characteristics such as speed limit, the presence or absence of rumble strip, passing ability, and the percentage of single unit trucks. The segments that were chosen were limited to average annual daily traffic (AADT) of more than 10,000 vehicles per day (vpd) and speed limit above 55 miles per hour (mph) in order to represent the rural two-lane highways in Utah. The CF of 1.16 was developed [4].

### 1.2.2. Illinois HSM Calibration

Illinois Department of Transportation (IDOT) developed HSM CFs using the Illinois local data considering differences in crash pattern and crash frequency [5]. Their calibration process focused on crash data from 2006 to 2011; however, the crash reporting threshold increased in 2009 from $500 to $1,500 for property damage only (PDO); therefore, the CFs were developed separately for years 2006 to 2008 and 2009 to 2011. Also, the crash frequency level and collision pattern for IDOT's one district compared to other nine districts were observed to be significantly different; therefore, for accuracy purposes, the Illinois SPF CFs were developed for this distinct area. They developed CFs based on the site and time period analyzed, Table 1.5:

**Table 1.5: Developed Calibration Factors in Illinois**

| | IDOT District 1 | | IDOT all other Districts | |
|---|---|---|---|---|
| | Three leg intersections with Stop Control | Two lane undivided arterial posted speed >30mph | Three leg intersections with Stop Control | Four-leg signalized in urban and suburban arterials |
| 2006-2008 | 0.35 | 3.65 | 0.24 | 3.22 |
| 2009-2011 | 0.23 | 2.89 | 0.24 | 2.32 |

### 1.2.3. Maine HSM Calibration

In the state of Maine, Maine DOT focused on developing local calibration factors for rural 2-lane road segments and intersections under the following steps [6]:

1. Select randomly sampled locations for each 2-lane facility type.
2. Gather attributes and recent actual crash data for each facility.
3. Calculate HSM crash predictions for each location.
4. Calculate CFs for each facility type.

For intersections, it was found that the HSM over-predicted the number of crashes by a factor of 2 compared to state of Maine crashes. Some of the developed CFs in Maine are shown in Table 1.6 [6].

**Table 1.6: Developed Calibration Factors in Maine**

| 2-Lane Rural Facility type | Calibration Factor |
|---|---|
| 3-Leg unsignalized intersection | 0.54 |
| 4-Leg unsignalized intersection | 0.38 |
| 4-Leg signalized intersection | 0.55 |

### 1.2.4. Maryland HSM Calibration

In Maryland, local CFs were developed to adjust predicted crashes for the Maryland-specific application of the HSM. CFs for all 18 facility types were calculated using Maryland local data [7]. After data collection and compilation, samples were drawn based on 90% confidence level, which increased the overall sample size. The CFs for all facilities were found to be less than 1.0, implying Maryland had fewer crashes than those predicted using HSM SPFs. Summary of the CFs developed in Maryland are as summarized in Table 1.7 [7]:

**Table 1.7: Developed Calibration Factors in Maryland**

| Segments | Calibration Factors | | Intersections | Calibration Factors |
|---|---|---|---|---|
| Undivided Rural Two-lane, Two-way Roadway Segments | 0.6956 | | Rural Two-Lane, Two-Way Road with Un-Signalized Three-leg Intersection | 0.1645 |
| Rural Four-Lane Undivided Segments | 2.3408 | | Rural Two-Lane, Two-Way Road with Un-signalized Four-leg Intersection | 0.2011 |
| Rural Four-lane Divided Segments | 0.5838 | | Rural Two-Lane, Two-Way Road with Signalized Four-leg Intersection | 0.2634 |
| Two-lane Undivided Urban and Suburban Arterial Segments | 0.6814 | | Rural Multilane Highway with Un-signalized Three-leg Intersection | 0.1788 |
| Three-lane Urban and Suburban Arterials including a Center TWLTL | 1.0785 | | Rural Multilane Highway with Un-signalized Four-leg Intersection | 0.3667 |
| Four-lane undivided arterials | 0.8788 | | Rural Multilane Highway with Signalized Four-leg Intersection | 0.1086 |
| Four-lane Divided Urban and Suburban Arterials | 0.8269 | | Urban and Suburban Arterial with Un-signalized Three-leg Intersection | 0.1562 |
| Five-lane arterials including a center TWLTL | 1.1891 | | Un-signalized four-leg intersection | 0.3824 |
| | | | Urban and Suburban Arterial with Signalized Three-leg Intersection | 0.3982 |
| | | | Urban and Suburban Arterial with Signalized four-leg intersection | 0.4782 |

### 1.2.5. Missouri HSM Calibration

In Missouri, the models calibrated included five roadway segments, eight intersection types, and three freeway segments types that are supposed to be part of the next edition of the HSM [8]. Three years of traffic and crash data from 2009-2011 were used in this calibration. The random sampling technique to ensure geographic representativeness across the state was used to select study sites. Some of the challenges encountered during calibration of SPFs for Missouri included data availability, obtaining a sufficient sample size for certain facility types, maintaining a balance between segment homogeneity and minimum segment length, and excluding inconsistent crash data. The calibration indicated that the HSM predicted Missouri crashes reasonably well, with the exception of a few facility types for which it may be desirable for Missouri to develop its own SPFs. The calibration factors for urban signalized intersections were high (ranging from 1.3 to 4.9), indicating that the number of crashes in Missouri is greater than those predicted through the HSM. The calibration factors for other facilities ranged from 0.28 (Rural multilane three leg stop controlled intersection) to 3.59 (urban four lane freeway segment). Some of the Missouri developed CFs are as shown in Table 1.8 [8].

**Table 1.8: Developed Calibration Factors in Missouri**

| Facility Type | Calibration Factor |
|---|---|
| Rural Two-Lane Undivided Highway Segments | 0.82 |
| Rural Multilane Divided Highway Segments | 0.98 |
| Urban Two-Lane Undivided Arterial Segments | 0.84 |
| Urban Four-Lane Divided Arterial Segments | 0.98 |
| Urban Five-Lane Undivided Arterial Segments | 0.73 |
| Urban Three-Leg Stop-Controlled Intersections | 1.06 |
| Urban Four-Leg Stop-Controlled Intersections | 1.3 |
| Rural Two-Lane Three-Leg Stop-Controlled Intersections | 0.77 |
| Rural Two-Lane Four-Leg Stop-Controlled Intersections | 0.49 |
| Rural Multilane Three-Leg Stop-Controlled Intersections | 0.28 |
| Rural Multilane Four-Leg Stop-Controlled Intersections | 0.39 |

### 1.2.6. Oregon HSM Calibration

In Oregon, HSM SPFs were calibrated for three facility types based on their historic safety performances [9]. Most of the CFs were much less than 1.00 for both segments and intersections. The results obtained from the State of Oregon gave an impression that Oregon facilities were generally safer than the national average. Summary of developed calibration factors in Oregon are shown in Table 1.9 [9].

**Table 1.9: Developed Calibration Factors in Oregon**

| Facility Type | Calibration Factor |
|---|---|
| 2-lane undivided Rural Two-Lane | 0.74 |
| Undivided Rural Multilane | 0.37 |
| Divided Rural Multilane | 0.77 |
| 2-lane undivided Urban and Suburban Arterials | 0.62 |
| 3-lane with TWLTL Urban and Suburban Arterials | 0.81 |
| 4-lane divided Urban and Suburban Arterials | 1.411 |
| 4-lane undivided Urban and Suburban Arterials | 0.64 |
| 5-lane with TWLTL Urban and Suburban Arterials | 0.63 |
| Rural Two-Lane 3-leg, minor STOP | 0.31 |
| Rural Two-Lane 4-leg, minor STOP | 0.31 |
| Rural Two-Lane 4-leg, signalized | 0.45 |
| Rural Multilane 3-leg, minor STOP | 0.15 |
| Rural Multilane 4-leg, minor STOP | 0.39 |
| Rural Multilane 4-leg, signalized | 0.15 |
| Urban and Suburban Arterials 3-leg, minor STOP | 0.35 |
| Urban and Suburban Arterials 4-leg, minor STOP | 0.45 |
| Urban and Suburban Arterials 3-leg, signalized | 0.73 |
| Urban and Suburban Arterials 4-leg, signalized | 0.63 |

### 1.2.7. Summary

Summary of CFs as developed in different states are shown in Table 1.10.

**Table 1.10: Summary of developed Calibration Factors from the Six States**

| FACILITY TYPE | Utah | Illinois | Maine | Maryland | Missouri | Oregon | Max | Min | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Rural Two-Lane, Two-Way road segment | 1.16 | 1.47 | 1.08 | 0.69 | 0.82 | 0.74 | 1.78 | 0.69 | 1.045 |
| Rural Two-Lane, Two-Way road Three-leg intersection with stop control | - | 0.24 | 0.54 | 0.16 | 0.77 | 0.31 | 0.77 | 0.16 | 0.404 |
| Rural Two-Lane, Two-Way Four-leg intersection with stop control | - | 0.31 | 0.38 | 0.20 | 0.49 | 0.31 | 0.49 | 0.20 | 0.336 |
| Rural Two-Lane, Two-Way Four-leg signalized intersection | - | 1.00 | 0.55 | 0.26 | - | 0.45 | 1.00 | 0.26 | 0.565 |
| Rural Multilane Highway Undivided four-lane roadway segment | - | 1.00 | - | 2.34 | - | 0.37 | 2.34 | 0.37 | 1.237 |
| Rural Multilane Highway Divided four-lane roadway segment | - | 1.30 | - | 0.58 | 0.98 | 0.77 | 1.30 | 0.58 | 0.908 |
| Rural Multilane Highway Three-leg intersection with stop control | - | 0.37 | - | 0.18 | 0.28 | 0.15 | 0.37 | 0.15 | 0.245 |
| Rural Multilane Highway Four-leg intersection with stop control | - | 0.60 | - | 0.37 | 0.39 | 0.39 | 0.60 | 0.37 | 0.438 |
| Rural Multilane Highway Four-leg signalized intersection | - | 1.00 | - | 0.11 | - | 0.15 | 1.00 | 0.11 | 0.420 |
| Urban and Suburban Arterial Two-lane undivided arterial Roadway Segment | - | 0.92 | - | 0.68 | 0.84 | 0.62 | 0.92 | 0.62 | 0.765 |
| Urban and Suburban Arterial Three-lane arterial Roadway Segment | - | 1.35 | - | 1.08 | - | 0.81 | 1.35 | 0.81 | 1.08 |
| Urban and Suburban Arterial Four-lane undivided arterial Roadway Segment | - | 1.17 | - | 0.88 | - | 0.64 | 1.17 | 0.64 | 0.897 |
| Urban and Suburban Arterial Four-lane divided arterial Roadway Segment | - | 1.36 | - | 0.83 | 0.98 | 1.41 | 1.41 | 0.83 | 1.145 |
| Urban and Suburban Arterial Five-lane arterial Roadway Segment | - | 0.97 | - | 1.19 | 0.73 | 0.63 | 1.19 | 0.63 | 0.88 |
| Urban and Suburban Arterial Three-leg intersection with stop control | - | 0.32 | - | 0.16 | - | 0.35 | 0.35 | 0.16 | 0.277 |
| Urban and Suburban Arterial Three-leg signalized intersection | - | 1.68 | - | 0.39 | - | 0.73 | 1.68 | 0.39 | 0.933 |
| Urban and Suburban Arterial Four-leg intersection with stop control | - | 0.63 | - | 0.38 | - | 0.45 | 0.63 | 0.38 | 0.486 |
| Urban and Suburban Arterial Four-leg signalized intersection | - | 2.32 | - | 0.48 | - | 0.63 | 2.32 | 0.48 | 1.143 |

# 2. DATA GATHERING AND ASSEMBLY

## 2.1. Two-Lane Two-Way Rural Intersections

The process started by identifying intersections in the state (3ST, 4ST and 4SG). A standard of at least 30 intersections for each category (statewide or regional) with at least 100 total crashes was considered adequate for analysis. The total number of 4SG intersections per TDOT region was less than 30 in Regions 1, 2, and 4, and was thus dropped from the analysis. Most of the study data was downloaded from E-TRIMS (https://e-trims.tdot.tn.gov/) including intersection inventory, locations, functional classes, number of lanes, observed number of crashes (2011 to 2015), and also the average annual daily traffic (AADTs) for both major and minor intersecting roadways (2011 to 2015 AADTs). The downloaded data was screened through STATA software and EXCEL to remove intersections that did not meet rural two-way two-lane intersection criteria and those which were missing AADT on both minor and major streets. TDOT's Image Viewer and Google Earth were used to verify intersection features used to estimate CMFs. These included the number of right-turn lanes, the number of left-turn lanes, the existence of lighting, and the skew angles used for the estimation of CMFs. Detailed data for two-lane, two-way rural intersections are in Appendix A.

### 2.1.1. Intersection Data

Different intersection types were identified through E-TRIMS including One way stop (3ST), Two way stop (4ST), and Signalized (4SG). Next, the intersections were filtered retaining only those on 2-lane rural highways. The intersections followed the following sub-categories and attributes:

- Intersection Inventory: Item code—One way stop (3ST), Two way stop (4ST), Signal (4SG)
- Road Geometrics: Number of Lanes = 02
- Road Segment: Administration System = Rural Roadways
- Traffic: Year = 2015 (Traffic for 2011 and 2014 were downloaded from TDOT traffic history website [10])

The downloaded intersections were further screened to remove the intersections which did not fit the two-lane rural highway classifications. This reduced the number of relevant intersections fitting the Rural Two-Lane Two-Way definition. The sample size for each category is:

- 3ST: 1716 intersections (hence 287 were selected randomly for analysis)
- 4ST: 196 intersections
- 4SG: 86 intersections

### 2.1.2. AADT Data

The E-TRIMS downloaded intersection data comes with variable titled "Description" which shows the Route IDs of the intersecting roadways. The AADTs were then downloaded using the nearest count station along the route to the intersection. The route under "Description" with the highest AADT was considered the Major Street and that with the lowest AADT as Minor Street. Five years of AADTs along Minor and Major Streets were then downloaded using the nearest count station along the route. While 2015 AADT was downloaded from E-TRIMS, the AADTs from 2011 to 2014 were downloaded from the TDOT Traffic history website [10]. The same AADT stations from 2015 AADT were used to get the data for 2011 to 2014. The 2011 to 2014 AADTs were then merged with those from 2015 using stations IDs, common for all years.

Analysis of AADT data showed that some of the intersections have missing AADTs along both the Minor and Major streets. Therefore, some of the intersections are dropped from the analysis, leaving the following number of intersections for final analysis:

- 3ST—238 intersections
- 4ST—195 intersections
- 4SG—71 intersections

Table 2.1 summarizes the number of intersections retained for analysis by type and by TDOT regions. Due to insufficient number of 4SG intersections for Regions 1, 2 and 4, the 4SG CFs are estimated for Statewide and Region 3 only. All the final intersections selected had AADTs within the following ranges as recommended in 2010 HSM for the intersection SPFs to be reliable:

- 3ST—$AADT_{maj}$ ranged from 0 to 19,500 vpd and $AADT_{min}$ range from 0 to 4,300 vpd
- 4ST—$AADT_{maj}$ ranged from 0 to 14,700 vpd and $AADT_{min}$ ranged from 0 to 3,500 vpd
- 4SG—$AADT_{maj}$ ranged from 0 to 25,200 vpd and $AADT_{min}$ ranged from 0 to 12,500 vpd

**Table 2.1: Number of Two-Lane Two-Way Intersections by TDOT Regions**

| Intersection Type | TDOT Region 1 | TDOT Region 2 | TDOT Region 3 | TDOT Region 4 | Total |
|---|---|---|---|---|---|
| 3ST | 60 | 53 | 66 | 59 | 238 |
| 4ST | 37 | 40 | 53 | 65 | 195 |
| 4SG | 9* | 18* | 33 | 11* | 71 |

*sample size below 30 intersections

### 2.1.3. Crash Data

Five years of crash data from 2011 to 2015 was downloaded from E-TRIMS in a combination of intersections inventory. This resulted with each crash being attached to the "Description" variable which shows the Route IDs of the intersecting roadways. Duplication of the crashes and intersection was screened to remain with unique crash ID. The "Description" variable from the CRASH DATA was therefore matched with "Description" in the final "INTERSECTION DATA." The number of crashes at each intersection type per year was then counted. The crash data was also counted per intersection type per TDOT region. Table 2.2 summarizes the number of crashes by years for the study retained intersections.

**Table 2.2: Number of Two-lane Two-way Crashes by Year and Intersection Type**

| Facility Type | Number of Intersections | Number of Crashes | | | | |
|---|---|---|---|---|---|---|
| | | 2011 | 2012 | 2013 | 2014 | 2015 |
| 3ST, minor STOP | 238 | 128 | 143 | 117 | 111 | 107 |
| 4ST, minor STOP | 195 | 233 | 243 | 189 | 181 | 149 |
| 4SG, Signalized | 71 | 177 | 199 | 181 | 186 | 189 |

The percentage distribution of Tennessee crashes by severity level for Rural Two-Lane Two-Way intersections were compared to those in the 2010 HSM. The percentages patterns are identical as shown in Table 2.3.

**Table 2.3: Distribution of Two-lane Two-way Crashes by Severity Level**

| Crash Severity Level | Intersection Type | | | | | |
|---|---|---|---|---|---|---|
| | 3ST | | 4ST | | 4SG | |
| | Proportion of total crashes (HSM Values) | Proportion of total crashes (TN Data) | Proportion of total crashes (HSM Values) | Proportion of total crashes (TN Data) | Proportion of total crashes (HSM Values) | Proportion of total crashes (TN Data) |
| Fatal | 1.70% | 1.32% | 1.80% | 2.41% | 0.90% | 0.21% |
| Incapacitating Injury | 4.00% | 5.45% | 4.30% | 8.84% | 2.10% | 3.00% |
| Other Injury | 35.80% | 27.06% | 37.00% | 34.97% | 31.00% | 22.85% |
| Total Fatal plus Injury | 41.50% | 33.83% | 43.10% | 46.22% | 34.00% | 26.06% |
| Property Damage Only | 58.50% | 66.17% | 56.90% | 53.78% | 66.00% | 73.93% |

### 2.1.4. Intersection geometrics

The HSM 2010 requires the CMFs to be determined for SPFs for the following intersection configurations and conditions. This process and CMF categories were also used for Multilane Rural Intersections.

- Intersection skew angles
- Presence or absence of lighting
- Presence of left turns approach and
- Presence of right turns approach

Therefore, TDOT Image Viewer and the Google Earth were used to manually view and estimate skew angles, presence of lighting, left turns, and right turns approaches. TDOT Image Viewer and the Google Earth also served as a confirmation step if the intersection met the 3ST, 4ST and 4SG specifications. Figure 2.1 illustrates how the TDOT Image Viewer was used.


**Figure 2.1: The Image Viewer Interface**

## 2.2. Rural Multilane Intersections Data

Detailed data for rural multilane intersections are in Appendix B.

### 2.2.1. Intersection Data

As was for two-lane two-way rural intersections, the gathering and downloading for rural multilane intersections follows the same procedures. This resulted into the following number of relevant intersections fitting the Rural Multilane definition:

- 3ST –52 intersections,
- 4ST—14 intersections and
- 4SG—254 intersections (hence 160 were selected randomly for analysis)

Due to unavailable AADTs along some Minor or Major streets, the following number of intersections were retained for final analysis:

- 3ST—36 intersections,
- 4ST—12 intersections and
- 4SG—158 intersections.

Table 2.4 summarizes the number of rural multilane intersections retained for analysis by type and by TDOT regions. As shown in Table 2.4 the sample size for 3ST and 4ST intersections are insufficient for regional analysis, hence the CFs are estimated for Statewide only. The AADTs of the retained intersections for rural multilane analysis are within the ranges recommended in 2010 HSM for the intersection SPFs to be reliable:

- 3ST—$AADT_{maj}$ ranged from 0 to 78,300 vpd and $AADT_{min}$ range from 0 to 23,000 vpd
- 4ST—$AADT_{maj}$ ranged from 0 to 78,300 vpd and $AADT_{min}$ ranged from 0 to 7,400vpd.
- 4SG—$AADT_{maj}$ ranged from 0 to 43,500 vpd and $AADT_{min}$ ranged from 0 to 18,500vpd

**Table 2.4: Number of Multilane Intersections by TDOT Regions**

| Intersection Type | TDOT Region 1 | TDOT Region 2 | TDOT Region 3 | TDOT Region 4 | Total |
|---|---|---|---|---|---|
| 3ST | 12* | 6* | 6* | 12* | 36 |
| 4ST | 2* | 0* | 2* | 8* | 12* |
| 4SG | 37 | 33 | 45 | 43 | 158 |

*sample size below 30 intersections

### 2.2.2. Crash Data

Table 2.5 summarizes the number of crashes at rural multilane intersections by year for the retained intersections. The percentage distribution of these crashes by severity level for rural multilane intersections is as shown in Table 2.6.

**Table 2.5: Number of Rural Multilane Crashes by Intersection Type**

| Facility Type | Number of Intersections | Number of Crashes | | | | |
|---|---|---|---|---|---|---|
| | | 2011 | 2012 | 2013 | 2014 | 2015 |
| 3ST, minor STOP | 36 | 81 | 62 | 74 | 61 | 64 |
| 4ST, minor STOP | 12 | 66 | 60 | 59 | 30 | 61 |
| 4SG, Signalized | 158 | 952 | 949 | 879 | 904 | 858 |

**Table 2.6: Distribution of Rural Multilane Crashes by Severity Level**

| Crash Severity Level | Proportion of total crashes (TN Data) | | |
|---|---|---|---|
| | 3ST | 4ST | 4SG |
| Fatal | 0.29% | 0.82% | 0.2% |
| Incapacitating Injury | 4.97% | 2.06% | 3.04% |
| Other Injury | 22.51% | 28.81% | 22.1% |
| Total Fatal plus Injury | 27.77% | 31.69% | 25.34% |
| Property Damage Only | 72.22% | 68.31% | 74.66% |

## 2.3. Urban and Suburban

The urban and suburban intersections are categorized as one way stop (3ST), two way stop (4ST), signalized four-leg (4SG), and signalized three-leg (3SG). Data was gathered following the procedures established for rural two-lanes and rural multilane. Detailed data are available in Appendix C.

### 2.3.1. Intersection Data

The downloading of AADTs resulted into some of the intersections missing AADT values along both the minor and major streets. This circumstance led to a decision to remove some of the intersections for final analysis. Table 2.7 summarizes the number of intersections retained for analysis. The intersections have AADTs within the following ranges as recommended in the HSM 2010 for reliability:

- 3ST—$AADT_{maj}$ ranged from 0 to 45,700 vpd and $AADT_{min}$ range from 0 to 9,300 vpd
- 4ST—$AADT_{maj}$ from 0 to 46,800 vpd and $AADT_{min}$ ranged from 0 to 5,900 vpd
- 3SG—$AADT_{maj}$ from 0 to 58,100 vpd and $AADT_{min}$ ranged from 0 to 16,400 vpd
- 4SG—$AADT_{maj}$ from 0 to 67,700 vpd and $AADT_{min}$ ranged from 0 to 33,400 vpd

The CMFs used to determine SPFs for the following intersection configurations and conditions for urban and suburban intersections include presence of lighting, presence of left turns approach, and presence of right turns approach. As for rural intersections, TDOT Image Viewer was used to manually view and estimate presence or absence of lighting, left turns, and right turns approaches.

**Table 2.7: Number of Urban/Suburban Intersection by Region**

| Intersection Type | TDOT Region 1 | TDOT Region 2 | TDOT Region 3 | TDOT Region 4 | Total |
|---|---|---|---|---|---|
| 3ST | 43 | 38 | 35 | 40 | 156 |
| 4ST | 38 | 30 | 30 | 40 | 138 |
| 3SG | 33 | 30 | 33 | 35 | 131 |
| 4SG | 42 | 41 | 41 | 41 | 165 |

### 2.3.2. Crash Data

Table 2.8 shows the number of multiple vehicle collision crashes on urban and suburban intersections, while Table 2.9 shows the number of single vehicle collision crashes.

**Table 2.8: Urban/Suburban Multiple Vehicles Collision Crashes**

| Facility Type | Number of Intersections | Number of Crashes | | | | |
|---|---|---|---|---|---|---|
| | | 2011 | 2012 | 2013 | 2014 | 2015 |
| 3ST, Minor STOP | 156 | 198 | 221 | 196 | 201 | 205 |
| 4ST, Minor STOP | 138 | 365 | 316 | 325 | 273 | 237 |
| 3SG, Signalized | 131 | 763 | 689 | 684 | 635 | 650 |
| 4SG, Signalized | 165 | 1505 | 1543 | 1429 | 1285 | 1241 |

**Table 2.9: Urban/Suburban Single Vehicle Collision Crashes**

| Facility Type | Number of Intersections | Number of Crashes | | | | |
|---|---|---|---|---|---|---|
| | | 2011 | 2012 | 2013 | 2014 | 2015 |
| 3ST, Minor STOP | 156 | 22 | 26 | 26 | 28 | 22 |
| 4ST, Minor STOP | 138 | 30 | 30 | 29 | 18 | 18 |
| 3SG, Signalized | 131 | 33 | 46 | 39 | 43 | 33 |
| 4SG, Signalized | 165 | 72 | 68 | 47 | 58 | 36 |

# 3. DEVELOPMENT OF CALIBRATION FACTORS (CFs)

Calibration factor is the ratio of the total observed crashes to the total SPF predicted crashes, determined as:

$$CF = \frac{\sum_{all\ sites} N_{observed}}{\sum_{all\ sites} N_{predicted(unadjusted)}} \qquad (3.1)$$

where;

$N_{Observed}$ : Total number of observed crushes during the study period

$N_{Predicted\ (Unadjusted)}$: Unadjusted total predicted crash frequency

## 3.1. HSM 2010 Intersections SPFs

Using the AADTs for minor and major streets and with the estimated CMFs, the predicted number of crashes was estimated using the HSM 2010 SPFs for 3ST, 4ST, 3SG and 4SG as follows:

### 3.1.1. HSM 2010 SPFs for Two-Lane Two-Way Intersections

$$N_{spf3ST} = exp\ \left[-9.86 + 0.79 \times ln\left(AADT_{maj}\right) + 0.49 \times ln\left(AADT_{min}\right)\right] * CMFs$$
$$N_{spf4ST} = exp\ [-8.56 + 0.6 \times ln\left(AADT_{maj}\right) + 0.61 \times ln\left(AADT_{min}\right)] * CMFs$$
$$N_{spf4S} = exp\ [-5.13 + 0.6 \times ln\ (AADT_{maj}) + 0.2 \times ln\ (AADT_{min}] * CMFs$$

### 3.1.2. HSM 2010 SPFs for Rural Multilane Intersections

$$N_{spf3ST} = exp\left[-12.526 + 1.204 \times ln\left(AADT_{maj}\right) + 0.236 \times ln\left(AADT_{min}\right)\right] * CMFs$$
$$N_{spf} = exp\ [-7.182 + 0.722 \times ln\left(AADT_{maj}\right) + 0.337 \times ln\left(AADT_{min}\right)] * CMFs$$
$$N_{spf4SG} = exp\ [-5.13 + 0.6 \times ln\ (AADT_{maj}) + 0.2 \times ln\ (AADT_{min}]$$

### 3.1.3. HSM 2010 SPFs for Urban/Suburban Intersections—Multivehicle Collisions

$$N_{spf3ST} = exp\ [-13.36 + 1.11 \times ln\left(AADT_{maj}\right) + 0.41\ ln\ (AADT_{min})\ ]$$
$$N_{spf3SG} = exp\ [-12.13 + 1.11 \times ln\left(AADT_{maj}\right) + 0.26\ ln\ (AADT_{min})\ ]$$
$$N_{spf4S} = exp\ [-8.90 + 1.07 \times ln\ ln\left(AADT_{maj}\right) + 023 \times ln\ (AADT_{min})\ ]$$
$$N_{spf4SG} = exp\ [-10.99 + 1.07 \times +0.23 \times ln\ (AADT_{min})\ ]$$

### 3.1.4. HSM 2010 SPFs for Urban/Suburban Intersections—Single Vehicle Collisions

$$N_{spf3ST} = exp\ [-6.81 + 0.61 \times ln\left(AADT_{maj}\right) + 0.51\ ln\ (AADT_{min})\ ]$$
$$N_{spf3}\quad exp\ [-9.02 + .42 \times ln\left(AADT_{maj}\right) + 0\ .4\ \ ln\ (AADT_{min})\ ]$$
$$N_{spf4ST} = exp\ [-5.3 + 0.3 \times ln\left(AADT_{maj}\right) + 0.12 \times ln\ (AADT_{min})\ ]$$
$$N_{spf4SG} = exp\ [-10.21 + 0.68 \times ln\left(AADT_{maj}\right) + 0.27 \times ln\ (AADT_{min})\ ]$$

## 3.2. Calibration Factors Calculation Approaches

The CFs were calculated using the observed crashes and the crashes predicted by the model for statewide data and each TDOT region, excluding areas where the sample size was insufficient. For comparison purposes, the CFs were calculated using the predicted crashes with and without the application of CMFs. Two approaches were used to calculate the CFs, which are discussed below.

**Approach 1** CFs for each year for five years was calculated and averaged:

- $CF_{2011}$: Estimated Calibration Factors using 2011 crashes and AADTs
- $CF_{2012}$: Estimated Calibration Factors using 2012 crashes and AADTs
- $CF_{2013}$: Estimated Calibration Factors using 2013 crashes and AADTs
- $CF_{2014}$: Estimated Calibration Factors using 2014 crashes and AADTs
- $CF_{2015}$: Estimated Calibration Factors using 2015 crashes and AADTs

Then yearly CFs was then averaged follows:

$$Calibration\ Factor\ (CF) \quad = \frac{CF_{2011} + CF_{2012} + CF_{2013} + CF_{2014} + CF_{2015}}{5} \qquad (3.2)$$

**Approach 2** used the five-year average AADTs in the prediction model. The CFs are calculated using the averaged crashes over five years and the prediction model using the averaged AADTs.

$$Calibration\ Factor\ (CF) = \frac{Averaged\ Observed\ Crashes}{Predicted\ using\ Averaged\ AADTs} \qquad (3.3)$$

## 3.3. Developed Calibration Factors (CFs)

Table 3.1 to Table 3.8 are the statewide and regional CFs calculated by applying CMFs to the prediction models. Also, the corresponding developed CFs with base prediction models (without the application of CMFs) is provided. As shown, the developed CFs for Rural Two-Lane Two-Way Intersections (3ST, 4ST and 4SG) are less than 1.0, indicating that Tennessee statewide and regional intersections (except 4ST in Region 2) have a smaller number of crashes than those predicted using HSM 2010 SPFs. The developed Tennessee intersection CFs are slightly higher than those developed in most states. The developed calibration factors for rural multilane and urban/suburban intersections are greater than one. Appendices summarize in detail the developed statewide CFs and for TDOT regions break down by analysis years.

**Table 3.1: Calibration Factors for Rural Two-Lane, Two-Way Intersections with CMF**

| **Using CMFs in the SPFs (Adjusted)** | | | | | |
|---|---|---|---|---|---|
| | **Tennessee Statewide** | **TDOT Region 1** | **TDOT Region 2** | **TDOT Region 3** | **TDOT Region 4** |
| Unsignalized three-leg (stop control on minor-road approaches) (3ST) | 0.633 | 0.542 | 0.654 | 0.773 | 0.646 |
| Unsignalized four-leg (stop control on minor-road approaches) (4ST) | 0.980 | 0.961 | 1.073 | 0.967 | 0.955 |
| Signalized four-leg (4SG) | 0.730 | ISD | ISD | 0.768 | ISD |
| *ISD: Insufficient Sample Size Data* | | | | | |

**Table 3.2: Calibration Factors for Rural Two-Lane, Two-Way Intersections without CMF**

| | **Tennessee Statewide** | **TDOT Region 1** | **TDOT Region 2** | **TDOT Region 3** | **TDOT Region 4** |
|---|---|---|---|---|---|
| Unsignalized three-leg (stop control on minor-road approaches) (3ST) | 0.514 | 0.391 | 0.495 | 0.685 | 0.500 |
| Unsignalized four-leg (stop control on minor-road approaches) (4ST) | 0.747 | 0.722 | 0.863 | 0.789 | 0.688 |
| Signalized four-leg (4SG) | 0.461 | ISD | ISD | 0.475 | ISD |
| *ISD= Insufficient Sample Size Data* | | | | | |

**Table 3.3: Calibration Factors for Rural Multilane Intersections with CMF**

| Using CMFs in the SPFs (Adjusted) | | | | | |
|---|---|---|---|---|---|
| | Tennessee Statewide | TDOT Region 1 | TDOT Region 2 | TDOT Region 3 | TDOT Region 4 |
| Unsignalized three-leg (stop control on minor-road approaches) (3ST) | 2.201 | ISD | ISD | ISD | ISD |
| Unsignalized four-leg (stop control on minor-road approaches) (4ST) | 1.959* | ISD | ISD | ISD | ISD |
| *ISD= Insufficient Sample Size Data* | | | | | |

**Table 3.4: Calibration Factors for Rural Multilane Intersections without CMF**

| | Statewide | Region 1 | Region 2 | Region 3 | Region 4 |
|---|---|---|---|---|---|
| Unsignalized three-leg (stop control on minor-road approaches) (3ST) | 1.215 | ISD | ISD | ISD | ISD |
| Unsignalized four-leg (stop control on minor-road approaches) (4ST) | 0.902* | ISD | ISD | ISD | ISD |
| Signalized four-leg (4SG) | 0.526 | 0.500 | 0.501 | 0.579 | 0.504 |
| *ISD= Insufficient Sample Size Data* | | | | | |

**Table 3.5: CFs for Urban and Suburban Intersections for Multiple Crash with CMF**

| Intersection Type | Statewide | Region 1 | Region 2 | Region 3 | Region 4 |
|---|---|---|---|---|---|
| Signalized Three legs Intersections3SG | 2.505 | 2.38 | 2.052 | 2.825 | 2.731 |
| Signalized Four legs Intersections 4SG | 2.622 | 2.366 | 2.372 | 2.635 | 2.941 |
| Three-leg Stop Control 3ST | 2.00 | 1.847 | 1.753 | 3.99 | 1.72 |
| Four-leg Stop Control 4ST | 1.834 | 2.164 | 1.989 | 1.583 | 1.75 |

**Table 3.6: CFs for Urban and Suburban Intersections for Multiple Crash without CMF**

| Intersection Type | Statewide | Region 1 | Region 2 | Region 3 | Region 4 |
|---|---|---|---|---|---|
| Signalized Three legs Intersections 3SG | 1.790 | 1.699 | 1.462 | 2.012 | 1.945 |
| Signalized Four legs Intersections 4SG | 1.780 | 1.605 | 1.609 | 1.787 | 1.994 |
| Three-leg Stop Control 3ST | 1.820 | 1.680 | 1.595 | 2.856 | 1.564 |
| Four-leg Stop Control 4ST | 1.668 | 1.970 | 1.810 | 1.441 | 1.592 |

**Table 3.7: CFs for Urban and Suburban Intersections for Single Crashes with CMF**

| Intersection Type | Statewide | Region 1 | Region 2 | Region 3 | Region 4 |
|---|---|---|---|---|---|
| Signalized Three legs Intersections 3SG | 1.805 | 1.091 | 1.684 | 2.551 | 2.118 |
| Signalized Four legs Intersections 4SG | 1.652 | 1.249 | 1.861 | 1.504 | 2.007 |
| Three-leg Stop Control 3ST | 0.819 | 0.574 | 0.419 | 0.93 | 1.294 |
| Four-leg Stop Control 4ST | 0.982 | 0.94 | 0.822 | 0.845 | 1.18 |

**Table 3.8: CFs for Urban and Suburban Intersections for Single Crashes Without CMF**

| Intersection Type | Statewide | Region 1 | Region 2 | Region 3 | Region 4 |
|---|---|---|---|---|---|
| Signalized Three legs Intersections 3SG | 1.289 | 0.777 | 1.199 | 1.817 | 1.508 |
| Signalized Four legs Intersections 4SG | 1.121 | 0.847 | 1.262 | 1.020 | 1.361 |
| Three-leg Stop Control 3ST | 0.746 | 0.522 | 0.381 | 0.733 | 1.175 |
| Four-leg Stop Control 4ST | 0.893 | 0.856 | 0.748 | 0.769 | 1.074 |

# 4. DEVELOPMENT OF TENNESSEE LOCAL SPFs

Using Tennessee crash data and AADTs, the study developed SPFs reflecting those developed in the HSM 2010 and compared the coefficients. The general form of the HSM 2010 SPF for Rural Two-Lane Two-Way Intersections is given as [12]:

$$N_{spf} = exp\ [\alpha + \beta 1 \times ln\left(AADT_{maj}\right) + \beta 2 \times ln(AADT_{min})]$$

where α is the constant and β1 and β2 are variable model coefficients. The HSM 2010 model coefficients are as shown in section 3.1.

Using Negative Binomial (NB) model, the study utilized Tennessee crash data for each of the intersection types to develop local SPF model constants and coefficients. The NB, which belongs to Generalized Linear Models family, was used due to its ability in linearizing the response variables with independent variables where the impacts are evaluated in terms of magnitude and sign of the independent variable. This enabled the development of SPFs with crash frequency as the response variable and AADTs as independent variables.

## 4.1. Developed SPFs for Two-Lane Two-Way Rural Intersections

### 4.1.1. SPF for Two-lane, Two-way Rural Unsignalized three-Leg (3ST) Intersections

Table 4.1 shows the developed unsignalized three-leg (stop control on minor-road approach) (3ST) SPF for two-lane two-way rural intersections. With all variables being significant, the sign and magnitude of the constant and coefficients are very close to the HSM 2010 model. As shown, the constant term is -9.25 (compared to -9.86 in HSM), the *ln*($AADT_{major}$) coefficient is 0.71 (compared to 0.76 in HSM) and the *ln*($AADT_{minor}$) coefficient is 0.41 (compared to 0.49 in HSM). The coefficients are slightly lower in the local SPF compared to HSM numbers. The corresponding Tennessee SPF for Rural Two-Lane, Two-Way unsignalized three-leg with stop control on minor-road approach (3ST) is given as;

$$N_{spf3S} = exp\left[-9.25 + 0.71 \times ln\left(AADT_{maj}\right) + 0.41 \times ln(AADT_{min})\right] \qquad (4.1)$$

**Table 4.1: Tennessee Data Developed SPF for Two-lane Rural 3ST**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.71 | 0.119 | 5.93 | 0.000 |
| ln ($AADT_{minor}$) | 0.41 | 0.129 | 3.15 | 0.002 |
| Constant | -9.25 | 1.045 | -8.85 | 0.000 |

### 4.1.2. SPF for Two-lane, Two-way Rural Unsignalized Four-Leg (4ST)

Table 4.2 illustrates the developed unsignalized four-leg (stop control on minor-road approaches) (4ST) SPF for two-lane two-way rural intersections. As was for 3ST, all variables are significant and the sign and magnitude of the constant and coefficients are very close to those in the 2010 HSM SPF. As shown the constant term is -7.01 (compared to -8.56 in HSM), the *ln* ($AADT_{major}$) coefficient is 0.44 (compared to 0.60 in HSM) and the *ln*($AADT_{minor}$) coefficient is 0.53 (compared to 0.61 in HSM). As was for 3ST, the 4ST coefficients are slightly lower in the local SPF developed compared to HSM numbers. The corresponding Tennessee SPF for Rural Two-Lane, Two-Way unsignalized four-leg with stop control on minor-road approaches (4ST) is therefore given as;

$$N_{spf4S} = exp\left[-7.01 + 0.44 \times ln\left(AADT_{maj}\right) + 0.53 \times ln(AADT_{min})\right] \qquad (4.2)$$

**Table 4.2: Tennessee Data Developed SPF for Two-lane Rural 4ST**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.44 | 0.09 | 4.92 | 0.000 |
| ln ($AADT_{minor}$) | 0.53 | 0.12 | 4.51 | 0.000 |
| Constant | -7.01 | 0.87 | -8.09 | 0.000 |

### 4.1.3. SPF for Two-lane, Two way Rural Signalized Four-Leg (4SG)

The developed SPF for Rural Two-Lane, Two-Way signalized four-leg intersections (4SG) using Tennessee data is shown in Table 4.3. Unlike 3ST and 4ST, the 4SG constant term and the coefficient magnitude of *ln($AADT_{minor}$)* are significantly different from those in the HSM 2010 SPF although the signs are identical. Furthermore, the *ln($AADT_{minor}$)* is not significant. However the sign and the magnitude of *ln($AADT_{major}$)* is almost identical to that in the HSM 2010 SPF. It should be noted that this intersection type did not have enough sample size in Regions 1, 2 and 4; hence low sample size may have impacted the model performance. As was found for 3ST and 4ST, the 4SG coefficients are slightly lower in the developed local SPF compared to HSM numbers. The corresponding Tennessee SPF for Rural Two-Lane, Two-Way signalized four-leg intersections (4SG) are therefore given as:

$$N_{spf4SG} = exp\ exp\left[-6.61 + 0.75 \times ln\ ln\left(AADT_{maj}\right) + 0.11 \times ln(AADT_{min})\right] \qquad (4.3)$$

**Table 4.3: Tennessee Data Developed SPF for Two-lane Rural 4SG**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.76 | 0.20 | 3.86 | 0.000 |
| ln ($AADT_{minor}$) | 0.11 | 0.10 | 1.10 | 0.271 |
| Constant | -6.61 | 1.77 | -3.73 | 0.000 |

## 4.2. Developed SPFs for Multilane Rural Intersections

### 4.2.1. Developed SPF for Rural Multilane Unsignalized three-Leg (3ST)

Table 4.4 shows the developed rural multilane unsignalized three-leg (stop control on minor-road approach) (3ST) SPF. With all variables not significant, the magnitude of the model constant and variable coefficients are different from the HSM 2010 model but with the same sign. As shown, the constant term is -3.985 (compared to -12.526 in HSM), the *ln($AADT_{major}$)* coefficient is 0.359 (compared to 1.204 in HSM) and the *ln($AADT_{minor}$)* coefficient is 0.175 (compared to 0.236 in HSM). The developed local SPF coefficients are lower compared to those in the HSM. It should be noted that the sample size for Multilane Rural intersections was low; hence that might have impacted the model coefficients compared to the HSM values. The corresponding Tennessee SPF for Rural Multilane unsignalized three-leg with stop control on minor-road approach (3ST) is therefore given as;

$$N_{spf3ST} = exp\left[-3.985 + 0.359 \times ln\left(AADT_{maj}\right) + 0.175 \times ln(AADT_{min})\right] \qquad (4.4)$$

**Table 4.4: Tennessee Data Developed SPF for Rural Multilane 3ST**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.359 | 0.275 | 1.3 | 0.193 |
| ln ($AADT_{minor}$) | 0.175 | 0.211 | 0.83 | 0.407 |
| Constant | -3.985 | 2.172 | -1.83 | 0.067 |

### 4.2.2. Developed SPF for Rural Multilane Unsignalized Four-Leg (4ST)

Shown in Table 4.5 is the developed SPF for rural multilane unsignalized four-leg (stop control on minor-road approaches) (4ST). The coefficients are significantly different from those in the HSM 2010 SPF but with the same sign. For instance, the constant term is -6.222 (compared to -10.008 in HSM), the *ln*($AADT_{major}$) coefficient is 0.042 (compared to 0.848 in HSM) and the *ln*($AADT_{minor}$) coefficient is 0.904 (compared to 0.448 in HSM). The 4ST constant coefficient and the *ln*($AADT_{major}$) coefficient are lower, while the *ln*($AADT_{minor}$) coefficient is higher in the local SPF developed compared to HSM numbers. The small sample size might have caused this differential in coefficients in comparison to the HSM. The corresponding Tennessee SPF for Rural Multilane unsignalized four-leg with stop control on minor-road approaches (4ST) is therefore given as;

$$N_{spf4ST} = exp\left[-6.222 + 0.042 \times ln\left(AADT_{maj}\right) + 0.904 \times ln(AADT_{min})\right] \qquad (4.5)$$

**Table 4.5: Tennessee Data Developed SPF for Rural Multilane 4ST**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.042 | 0.614 | 0.07 | 0.945 |
| ln ($AADT_{minor}$) | 0.904 | 0.368 | 2.46 | 0.014 |
| Constant | -6.222 | 5.995 | -1.04 | 0.299 |

### 4.2.3. Developed SPF for Rural Multilane Signalized Four-Leg (4SG)

The developed SPF for Rural Multilane signalized four-leg intersections (4SG) using Tennessee data is shown in Table 4.6. All variables are significant, and the magnitudes of the constant and coefficients are relatively comparable with those in the HSM 2010 SPF including the coefficient signs. As shown in Table 4.6, the constant term is -8.641 (compared to -7.182 in HSM), the *ln* ($AADT_{major}$) coefficient is 0.837 (compared to 0.722 in HSM) and the *ln*($AADT_{minor}$) coefficient is 0.300 (compared to 0.337 in HSM). The coefficients are lower in the local SPF compared to HSM numbers. As was for 3ST and 4ST, the 4SG coefficients are slightly higher in the local SPF developed compared to HSM numbers, except the *ln*($AADT_{minor}$) coefficient which is slightly closer. The corresponding Tennessee SPF for Rural Multilane signalized four-leg intersections (4SG) are therefore given as:

$$N_{spf4SG} = exp\left[-8.641 + 0.837 \times ln\left(AADT_{maj}\right) + 0.300 \times ln(AADT_{min})\right] \qquad (4.6)$$

**Table 4.6: Tennessee Data Developed SPF for Rural Multilane 4SG**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.837 | 0.108 | 7.73 | 0 |
| ln ($AADT_{minor}$) | 0.300 | 0.056 | 5.38 | 0 |
| Constant | -8.641 | 0.977 | -8.84 | 0 |

## 4.3. Developed SPFs for Urban/Suburban Intersections

### 4.3.1. SPFs for Urban/Suburban Signalized Four-Leg (4SG)

Table 4.7 and 4.8 shows the developed urban/suburban signalized four-leg (4SG) SPF for Single and Multiple Vehicle collisions, respectively. All variables in the Single Vehicle collision models are insignificant, while all variables in the Multiple Vehicle collision model are significant. The sign of the model's constants and variables are the same as those of the HSM, but the magnitude differ significantly except for *ln*($AADT_{minor}$) coefficient which is close to that in the HSM. As shown on the Single Vehicle collision model, the constant term is -5.39 (compared to -10.21 in HSM), the *ln* ($AADT_{major}$) coefficient is 0.17 (compared to 0.68 in HSM) and the *ln* ($AADT_{minor}$)coefficient is 0.31 (compared to 0.27 in HSM). For the Multiple vehicle collision model, the constant term is -7.38 (compared to -10.99 in HSM), the *ln*($AADT_{major}$) coefficient is 0.58 (compared to 1.07 in HSM) and the *ln*($AADT_{minor}$) coefficient is 0.43 (compared to 0.23 in HSM).

The corresponding Tennessee SPF for Urban and Suburban signalized four-leg intersections (4SG) for Single Vehicle Collisions is as shown in equation 4.7;

$$N_{spf} \quad = exp\left[-5.39 + 0.17 \times ln\left(AADT_{maj}\right) + 0.31 \times ln(AADT_{min})\right] \qquad (4.7)$$

**Table 4.7: Tennessee Data Developed SPF Urban 4SG for Single Vehicle Collision**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.17 | 0.263 | 0.63 | 0.529 |
| ln ($AADT_{minor}$) | 0.31 | 0.212 | 1.47 | 0.142 |
| Constant | -5.39 | 2.459 | -2.19 | 0.028 |

The corresponding Tennessee SPF for Urban and Suburban signalized four-leg intersections (4SG) for Multivehicle Vehicle Collisions is as shown in equation 4.8;

$$N_{spf4SG} = exp\left[-7.38 + 0.58 \times ln\, ln\left(AADT_{maj}\right) + 0.43 \times ln(AADT_{min})\right] \qquad (4.8)$$

**Table 4.8: Tennessee Data Developed SPF Urban 4SG for Multiple Vehicle Collision**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.58 | 0.109 | 5.37 | 0 |
| ln ($AADT_{minor}$) | 0.43 | 0.082 | 5.3 | 0 |
| Constant | -7.38 | 1.042 | -7.08 | 0 |

### 4.3.2. SPFs for Urban/Suburban Signalized Three-Leg (3SG)

Table 4.9 and 4.10 show the developed urban/suburban signalized three-leg (3SG) SPF for Single and Multiple Vehicle collisions, respectively. All the variables in the Single Vehicle collisions models are not significant (Z-values less than 1.96 for 95% significance level) while Multiple Vehicle collisions model coefficients are significant. The sign of the model's constants and variables are the same as those of the HSM. For Single Vehicle collision model, the constant term is -5.97 (compared to -9.02 in HSM), the *ln*($AADT_{minor}$) coefficient is 0.36 (compared to 0.42 in HSM) and the *ln*($AADT_{minor}$) coefficient is 0.14 (compared to 0.40 in HSM). For the Multiple vehicle collision model, the constant term is -8.54 (compared to -12.13 in HSM), the *ln*($AADT_{minor}$) coefficient is 0.82 (compared to 1.11 in HSM) and the *ln*($AADT_{minor}$) coefficient is 0.25 (compared to 0.26 in HSM). The corresponding Tennessee SPF for Urban and Suburban signalized three-leg intersections (3SG) for Single Vehicle Collisions is as shown in equation 4.9;

$$N_{spf4SG} = exp\left[-5.97 + 0.36 \times ln\left(AADT_{maj}\right) + 0.14 \times ln(AADT_{min})\right] \qquad (4.9)$$

**Table 4.9: Tennessee Data Developed SPF Urban 3SG for Single Vehicle Collision**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.36 | 0.354 | 1.02 | 0.306 |
| ln ($AADT_{minor}$) | 0.14 | 0.168 | 0.86 | 0.392 |
| Constant | -5.97 | 3.138 | -1.9 | 0.057 |

The developed Tennessee SPF for Urban and Suburban signalized four-leg intersections (3SG) for Multivehicle Vehicle Collisions is as shown in equation 4.10;

$$N_{spf4S} \quad = exp\left[-8.54 + 0.82 \times ln\left(AADT_{maj}\right) + 0.25 \times ln(AADT_{min})\right] \qquad (4.10)$$

**Table 4.10: Tennessee Data Developed SPF Urban 3SG for Multiple Vehicle Collision**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.82 | 0.135 | 6.06 | 0.000 |
| ln ($AADT_{minor}$) | 0.25 | 0.062 | 4.01 | 0.000 |
| Constant | -8.54 | 1.239 | -6.89 | 0.000 |

### 4.3.3. SPFs for Urban/Suburban Un-Signalized Four-Leg (4ST)

Table 4.11 and 4.12 shows the developed urban/suburban unsignalized four-leg (stop control on minor-road approach) (4ST) SPFs for Single and Multiple Vehicle collisions, respectively. The sign of the model's constants and coefficients are the same as those of the HSM but vary slightly in magnitude. For the Single Vehicle collision model, the constant term is -3.16 (compared to -5.33 in HSM), the $ln(AADT_{major})$ coefficient is 0.11 (compared to 0.33 in HSM) and the $ln(AADT_{minor})$ coefficient is 0.08 (compared to 0.12 in HSM). For Multiple vehicle collision model, the constant term is -5.36 (compared to -8.90 in HSM), the $ln(AADT_{major})$ coefficient is 0.25 (compared to 0.82 in HSM) and the $ln(AADT_{minor})$ coefficient is 0.54 (compared to 0.25 in HSM). The corresponding Tennessee SPF for Urban and Suburban unsignalized four-leg with stop control on minor-roads approaches (4ST) for Single Vehicle Collisions is as given in equation 4.11;

$$N_{spf4ST} = exp\ exp\left[-3.16 + 0.11 \times ln\ ln\left(AADT_{maj}\right) + 0.08 \times ln(AADT_{min})\right] \quad (4.11)$$

**Table 4.11: Tennessee Data Developed SPF Urban 4ST for Single Vehicle Collision**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.11 | 0.216 | 0.5 | 0.615 |
| ln ($AADT_{minor}$) | 0.08 | 0.249 | 0.32 | 0.746 |
| Constant | -3.16 | 2.168 | -1.46 | 0.145 |

The corresponding Tennessee SPF for Urban and Suburban unsignalized four-leg with stop control on minor-roads approaches (4ST) for Multiple Vehicle Collisions is as given in equation 4.12;

$$N_{spf4ST} = exp\ exp\left[-5.36 + 0.25 \times ln\ ln\left(AADT_{maj}\right) + 0.54 \times ln(AADT_{min})\right] \quad (4.12)$$

**Table 4.12: Tennessee Data Developed SPF Urban 4ST for Multiple Vehicle Collision**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.25 | 0.078 | 3.21 | 0.001 |
| ln ($AADT_{minor}$) | 0.54 | 0.095 | 5.72 | 0.000 |
| Constant | -5.36 | 0.855 | -6.27 | 0.000 |

### 4.3.4. SPFs for Urban/Suburban Un-Signalized Four-Leg (3ST)

Table 4.13 and 4.14 shows the developed urban/suburban unsignalized three-leg (stop control on minor-road approach) (3ST) SPF for Single and Multiple Vehicle collisions respectively. The Sign of the model’s constants and variables are the same as those of the HSM but vary in magnitude. As shown, for Single Vehicle collision model, the constant term is -3.95 (compared to -6.81 in HSM), the $ln\ (AADT_{major})$ coefficient is 0.10 (compared to 0.16 in HSM) and the $ln\ (AADT_{minor})$ coefficient is 0.17 (compared to 0.51 in HSM). For Multiple vehicle collisions model, the constant term is -4.84 (compared to -13.36 in HSM), the major road AADT coefficient is 0.13 (compared to 1.11 in HSM) and the minor road AADT coefficient is 0.52 (compared to 0.41 in HSM). The corresponding Tennessee SPF for Urban and Suburban unsignalized three-leg with stop control on minor-road approach (3ST) for Single Vehicle Collisions is therefore given as shown in equation 4.13;

$$N_{spf3ST} = exp\ \left[-3.95 + 0.10 \times ln\left(AADT_{maj}\right) + 0.17 \times ln(AADT_{min})\right] \quad (4.13)$$

**Table 4.13: Tennessee Data Developed SPF Urban 3ST for Single Vehicle Collision**

| Variables | Coefficients | Std. Err. | z | P>z |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.10 | 0.264 | 0.38 | 0.706 |
| ln ($AADT_{minor}$) | 0.17 | 0.282 | 0.60 | 0.552 |
| Constant | -3.95 | 2.107 | -1.87 | 0.061 |

The developed Tennessee SPF for Urban and Suburban unsignalized three-leg with stop control on minor-road approach (3ST) for Multiple Vehicle Collisions is given as shown in equation 4.14;

$$N_{spf3ST} = exp\left[-4.84 + 0.13 \times ln\left(AADT_{maj}\right) + 0.52 \times ln(AADT_{min})\right] \qquad (4.14)$$

**Table 4.14: Tennessee Data Developed SPF Urban 3ST for Multiple Vehicle Collision**

| **Variables** | **Coefficients** | **Std. Err.** | **z** | **P>z** |
|---|---|---|---|---|
| ln ($AADT_{major}$) | 0.13 | 0.106 | 1.23 | 0.22 |
| ln ($AADT_{minor}$) | 0.52 | 0.116 | 4.49 | 0.00 |
| Constant | -4.84 | 0.873 | -5.54 | 0.00 |

# 5. SUMMARY

This research developed Calibration Factors (CFs) for three types of intersections with Safety Performance Functions (SPFs) in the HSM 2010 including Rural Two-Lane Two-Way intersections, Rural Multilane intersections, and Urban/Suburban intersections. Also developed are the corresponding SPFs using Tennessee data. Study data for intersections, crash, and AADT was downloaded from the TDOT-managed E-TRIMS database which stores intersection inventory, locations, roadway functional classes, number of lanes, crashes, and the average annual daily traffic (AADTs) for both major and minor intersecting roadways. Study intersections were identified in E-TRIMS as unsignalized three leg one way stop (3ST), unsignalized four leg two way stop (4ST), three signalized (3SG), and four leg signalized (4SG). The TDOT Image Viewer and the Google Earth were used to estimate and confirm the existence of intersection skew angles, the presence of intersection lighting, left turn lanes, and right turn lanes which were used for the determination of CMFs. The calibration factors were developed using five years (2011-2015) of statewide and regional traffic and crash data. The factors were developed both for the entire state and each TDOT region (except in the cases with insufficient sample size for TDOT regions).

The statewide CFs for Rural Two-Lane, Two-Way Intersections are:
- 0.633 for Unsignalized three-leg (stop control on minor-road approaches) (3ST)
- 0.980 for Unsignalized four-leg (stop control on minor-road approaches) (4ST) and
- 0.730 for Signalized four-leg (4SG).

The statewide CFs for Rural Multilane Intersections are:
- 2.201 for Unsignalized three-leg (stop control on minor-road approaches) (3ST)
- 1.959 for Unsignalized four-leg (stop control on minor-road approaches) (4ST) and
- 0.526 for Signalized four-leg (4SG) (without application of CMF)

The statewide CFs for Urban/Suburban Intersections Single Vehicle Collisions are:
- 1.805 for Unsignalized three-leg (stop control on minor-road approaches) (3ST)
- 1.652 for Unsignalized four-leg (stop control on minor-road approaches) (4ST)
- 0.819 for Signalized three-leg (3SG)
- 0.982 for Signalized four-leg (4SG)

The statewide CFs for Urban/Suburban Intersections Multiple Vehicle Collisions are:
- 2.505 for Unsignalized three-leg (stop control on minor-road approaches) (3ST)
- 2.622 for Unsignalized four-leg (stop control on minor-road approaches) (4ST)
- 2.000 for Signalized three-leg (3SG)
- 1.834 for Signalized four-leg (4SG)

The developed CFs show that Tennessee has fewer Rural Two-Lane Two-Way intersection-related crashes compared to those estimated using the HSM 2010 SPFs. For instance, crashes on unsignalized three-leg intersections (stop control on minor-road approaches, 3ST) are only 63.3% of those predicted through the HSM SPF, 98% for unsignalized four-leg intersections (stop control on minor-road approaches, 4ST) and 73% for signalized four-leg intersections (4SG).

Rural multilane intersections and urban/suburban intersections have a larger number of predicted crashes compared to those using the HSM 2010, as most of the CFs for intersections within these two categories are greater than 1.0. However, signalized intersections in urban and suburban areas with single vehicle collisions (3SG and 4SG) have fewer crashes compared to HSM 2010 SPF predictions (CFs less than 1.00).

Using Tennessee crash data, the study developed SPFs reflecting those developed in the HSM 2010. Utilizing the Negative Binomial model, the study used Tennessee crash and AADT data for each of the intersection types to develop local constants and coefficients. The sign and magnitude of the model constant and variable coefficients of the developed SPFs were very close to those in the 2010 HSM. The Tennessee developed SPFs are:

Tennessee SPFs for Rural Two-Lane Two-Way Intersections

$$N_{spf} = exp\left[-9.25 + 0.71 \times ln\left(AADT_{maj}\right) + 0.41 \times ln(AADT_{min})\right]$$
$$N_{spf4S} = exp\,[-7.01 + 0.44 \times ln\left(AADT_{maj}\right) + 0.53 \times ln(AADT_{min})]$$
$$N_{spf4S} = exp\,[-6.61 + 0.75 \times ln\left(AADT_{maj}\right) + 0.11 \times ln(AADT_{min})]$$

Tennessee SPFs for Rural Multilane Intersections

$$N_{spf3ST} = exp\left[-3.985 + 0.359 \times ln\, ln\left(AADT_{maj}\right) + 0.175 \times ln(AADT_{min})\right]$$
$$N_{spf} = exp\left[-6.222 + 0.042 \times ln\, ln\left(AADT_{maj}\right) + 0.904 \times ln(AADT_{min})\right]$$
$$N_{spf4SG} = exp\left[-8.641 + 0.837 \times ln\, ln\left(AADT_{maj}\right) + 0.300 \times ln(AADT_{min})\right]$$

Tennessee SPFs for Urban Intersections for Single Vehicle Collision

$$N_{spf4SG} = exp\left[-5.39 + 0.17 \times ln\left(AADT_{maj}\right) + 0.31 \times ln(AADT_{min})\right]$$
$$N_{spf3S} = exp\left[-5.97 + 0.36 \times ln\left(AADT_{maj}\right) + 0.14 \times ln(AADT_{min})\right]$$
$$N_{spf4S} = exp\left[-3.16 + 0.11 \times ln\left(AADT_{maj}\right) + 0.08 \times ln(AADT_{min})\right]$$
$$N_{spf3ST} = exp\left[-3.95 + 0.10 \times ln\left(AADT_{maj}\right) + 0.17 \times ln(AADT_{min})\right]$$

Tennessee SPFs for Urban Intersections for Multiple Vehicle Collisions

$$N_{spf4SG} = exp\left[-7.38 + 0.58 \times ln\left(AADT_{maj}\right) + 0.43 \times ln(AADT_{min})\right]$$
$$N_{spf3SG} = exp\left[-8.54 + 0.82 \times ln\left(AADT_{maj}\right) + 0.25 \times ln(AADT_{min})\right]$$
$$N_{spf4ST} = exp\left[-5.36 + 0.25 \times ln\left(AADT_{maj}\right) + 0.54 \times ln(AADT_{min})\right]$$
$$N_{spf3S} = exp\left[-4.84 + 0.13 \times ln\left(AADT_{maj}\right) + 0.52 \times ln(AADT_{min})\right]$$

# 6. REFERENCES


[1] American Association Of State Highway and Transportation Officials (AASHTO), "Highway Safety Manual," Washington, D.C, 2010.

[2] American Association of State Highway and Transportation Officials (AASHTO), "Highway Safety Manual (HSM)," AASHTO, 2010.

[3] Florida Department of Transportation (FDOT), "2015 Highway Safety Matrix," 2015, http://www.dot.state.fl.us/safety/3-Grants/Grants-Home.shtm.

[4] B. K. Brimley, M. Saito and G. G. Schultz, "Calibration of Highway Safety Manual Safety Performance Function," *Transportation Research Record: Journal of the Transportation Research Board,* vol. 2279, pp. 82-89, 2012.

[5] (IDOT), Illinois Department of Transportation, "AASHTO Highway Safety Manual Illinois User Guide," IDOT, 2014.

[6] MaineDOT, "Highway Safety Manual Local Calibration for Rural 2-Lane Road Segments and Intersections," http://www.maine.gov/mdot/tr/docs/rtb06262015.pdf , 2014.

[7] H. Shin, Y.-J. Lee and S. Dadvar, "The Development of Local Calibration Factors for Implementing the Highway Safety Manual in Maryland," State Highway Administration (SHA) - Maryland Department of Transportation-, 2014.

[8] C. Sun and P. E. Henry Brown, "Calibration of the Highway Safety Manual for Missouri," Missouri Department of Transportation, 2014.

[9] F. Xie, K. Gladhill, K. K. Dixon and C. M. Monsere, "Calibrating the Highway Safety Manual Predictive Models for Oregon State Highway," Washington, DC, 2011.

[10] Tennessee Department of Transportation (TDOT), "Traffic History," [Online]. Available: https://www.tdot.tn.gov/APPLICATIONS/traffichistory. [Accessed April 2017].

[11] A. Farid, M. Abdel-Aty, J. Lee, N. Eluru and J.-H. Wang, "Exploring the transferability of safety performance functions," *Accident Analysis and Prevention,* vol. 94, pp. 143-152, 2016.

[12] D. Saha, P. Alluri and A. Gan, "A Bayesian procedure for evaluating the frequency of calibration factor updates in highway safety manual (HSM) applications," *Accident Analysis and Prevention,* vol. 98, pp. 74-86, 2016.

[13] M. Williamson and H. Zhou, "Develop Calibration Factors for Crash Prediction Models for Rural Two-Lane Roadways in Illinois," *Social and Behavioral Sciences,* vol. 43, p. 330 – 338, 2012.

[14] S. Cafiso, G. D. Silvestro and G. D. Guardo, "Application of Highway Safety Manual to Italian divided multilane highways," *Social and Behavioral Sciences,* vol. 53, p. 911 – 920, 2012.

[15] I. D. o. T. (IDOT), "AASHTO Highway Safety Manual Illinois User Guide," IDOT, 2014.

# 7. APPENDIX

# APPENDIX A: TWO-LANE TWO WAY INTERSECTIONS DATA

**Table A1: Summary of the results for Tennessee Rural Two-Lane, Two-Way Intersections Calibration Factors—With CMFs**

| | Tennessee Calibration Factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Tennessee Statewide | | TN Region 1 | | TN Region 2 | | TN Region 3 | | TN Region 4 | |
| Rural Two-Lane Intersections | **A:** Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model | **A:** Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model | A: Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model | A: Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model l | A: Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model |
| Unsignalized three-leg (stop control on minor-road approaches) (3ST) | 0.633 | 0.636 | 0.542 | 0.540 | 0.472 | 0.522 | 0.773 | 0.765 | 0.646 | 0.644 |
| Unsignalized four-leg (stop control on minor-road approaches) (4ST) | 0.980 | 0.978 | 0.961 | 0.958 | 0.971 | 1.078 | 0.967 | 0.967 | 0.955 | 0.925 |
| Signalized four-leg (4SG) | 0.730 | 0.728 | ISD | ISD | ISD | ISD | 0.768 | 0.767 | ISD | ISD |
| | ISD= Insufficient Sample Size Data (we are still searching if we can find more 4SG intersections) | | | | | | | | | |

**Table A2: Summary of the results for Tennessee Rural Two-Lane, Two-Way Intersections Calibration Factors—No CMFs**

| | Tennessee Calibration Factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Tennessee Statewide | | TN Region 1 | | TN Region 2 | | TN Region 3 | | TN Region 4 | |
| Rural Two-Lane Intersections | **A:** Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model | **A:** Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model | A: Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model | A: Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model | A: Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model |
| Unsignalized three-leg (stop control on minor-road approaches) (3ST) | 0.514 | 0.513 | 0.391 | 0.396 | 0.495 | 0.496 | 0.685 | 0.679 | 0.500 | 0.499 |
| Unsignalized four-leg (stop control on minor-road approaches) (4ST) | 0.747 | 0.745 | 0.722 | 0.719 | 0.863 | 0.791 | 0.789 | 0.788 | 0.688 | 0.687 |
| Signalized four-leg (4SG) | 0.461 | 0.459 | ISD | ISD | ISD | ISD | 0.475 | 0.475 | ISD | ISD |
| | ISD= Insufficient Sample Size Data (we are still searching if we can find more 4SG intersections) | | | | | | | | | |

**Table A3: Estimated CFs for Rural Two Way Two Lane Intersections statewide with CMF**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 238 | 128 | 191 | 143 | 186 | 117 | 193 | 111 | 191 | 107 | 189 | 0.67 | 0.77 | 0.61 | 0.58 | 0.57 | 0.64 |
| 4-leg, minor STOP | 195 | 233 | 206 | 243 | 208 | 189 | 201 | 181 | 196 | 149 | 202 | 1.13 | 1.17 | 0.94 | 0.92 | 0.74 | 0.98 |
| 4-leg, signalized | 70 | 177 | 261 | 199 | 256 | 181 | 254 | 186 | 249 | 189 | 256 | 0.68 | 0.78 | 0.71 | 0.75 | 0.74 | 0.73 |

**Table A4: Estimated CFs for Rural Two Way Two Lane Intersections Region 1 with CMF**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 60 | 32 | 63 | 33 | 62 | 29 | 60 | 47 | 60 | 25 | 62 | 0.51 | 0.53 | 0.48 | 0.78 | 0.40 | 0.54 |
| 4-leg, minor STOP | 37 | 57 | 43 | 44 | 43 | 41 | 42 | 38 | 42 | 24 | 43 | 1.33 | 1.03 | 0.98 | 0.90 | 0.56 | 0.96 |
| 4-leg, signalized | | | | | | | | | | | | | | | | | |

**TableA5: Estimated CFs for Rural Two Way Two Lane Intersections Region 2 with CMF**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 53 | 31 | 41 | 32 | 41 | 20 | 43 | 22 | 43 | 19 | 43 | 0.76 | 0.79 | 0.47 | 0.51 | 0.44 | 0.59 |
| 4-leg, minor STOP | 40 | 52 | 45 | 65 | 48 | 44 | 45 | 49 | 43 | 37 | 45 | 1.14 | 1.36 | 0.98 | 1.13 | 0.82 | 1.09 |
| 4-leg, signalized | | | | | | | | | | | | | | | | | |

**Table A6: Estimated CFs for Rural Two Way Two Lane Intersections Region 3 with CMF**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 66 | 50 | 58 | 57 | 56 | 56 | 64 | 23 | 63 | 44 | 59 | 0.86 | 1.01 | 0.88 | 0.37 | 0.75 | 0.77 |
| 4-leg, minor STOP | 53 | 61 | 59 | 72 | 59 | 54 | 55 | 51 | 56 | 41 | 57 | 1.03 | 1.21 | 0.98 | 0.91 | 0.72 | 0.97 |
| 4-leg, signalized | 33 | 88 | 122 | 101 | 121 | 95 | 124 | 89 | 122 | 97 | 123 | 0.72 | 0.83 | 0.77 | 0.73 | 0.79 | 0.77 |

**Table A7: Estimated CFs for Rural Two Way Two Lane Intersections Region 4 with CMF**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 59 | 15 | 28 | 21 | 27 | 12 | 26 | 19 | 26 | 19 | 26 | 0.53 | 0.77 | 0.46 | 0.73 | 0.73 | 0.65 |
| 4-leg, minor STOP | 65 | 63 | 58 | 62 | 58 | 50 | 58 | 43 | 55 | 47 | 56 | 1.08 | 1.06 | 0.86 | 0.78 | 0.84 | 0.93 |
| 4-leg, signalized | | | | | | | | | | | | | | | | | |

**Table A8: Estimated CFs for Rural Two Way Two Lane Intersections statewide without CMFs**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 238 | 128 | 237 | 143 | 233 | 117 | 237 | 111 | 235 | 107 | 236 | 0.54 | 0.61 | 0.49 | 0.47 | 0.45 | 0.51 |
| 4-leg, minor STOP | 195 | 233 | 271 | 243 | 275 | 189 | 263 | 181 | 256 | 149 | 264 | 0.86 | 0.88 | 0.72 | 0.71 | 0.56 | 0.75 |
| 4-leg, signalized | 70 | 177 | 413 | 199 | 406 | 181 | 403 | 186 | 395 | 189 | 406 | 0.43 | 0.49 | 0.45 | 0.47 | 0.47 | 0.46 |

**Table A9: Estimated CFs for Rural Two Way Two Lane Intersections Region 1 without CMFs**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 60 | 32 | 87 | 33 | 85 | 29 | 82 | 47 | 81 | 25 | 84 | 0.37 | 0.39 | 0.36 | 0.58 | 0.30 | 0.40 |
| 4-leg, minor STOP | 37 | 57 | 57 | 44 | 58 | 41 | 56 | 38 | 55 | 24 | 57 | 1.00 | 0.76 | 0.74 | 0.69 | 0.42 | 0.72 |
| 4-leg, signalized | | | | | | | | | | | | | | | | | |

**Table A10: Estimated CFs for Rural Two Way Two Lane Intersections Region 2 without CMFs**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 53 | 31 | 49 | 32 | 49 | 20 | 51 | 22 | 51 | 19 | 50 | 0.64 | 0.66 | 0.39 | 0.43 | 0.38 | 0.50 |
| 4-leg, minor STOP | 40 | 52 | 64 | 65 | 66 | 44 | 61 | 49 | 57 | 37 | 61 | 0.82 | 0.98 | 0.72 | 0.86 | 0.61 | 0.80 |
| 4-leg, signalized | | | | | | | | | | | | | | | | | |

**Table A11: Estimated CFs for Rural Two Way Two Lane Intersections Region 3 without CMFs**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 66 | 50 | 68 | 57 | 66 | 56 | 71 | 23 | 70 | 44 | 68 | 0.74 | 0.87 | 0.79 | 0.33 | 0.65 | 0.68 |
| 4-leg, minor STOP | 53 | 61 | 72 | 72 | 73 | 54 | 68 | 51 | 69 | 41 | 71 | 0.85 | 0 | 0.79 | 0.74 | 0.58 | 0.79 |
| 4-leg, signalized | 33 | 88 | 197 | 101 | 196 | 95 | 200 | 89 | 197 | 97 | 199 | 0.45 | 0.52 | 0.48 | 0.45 | 0.49 | 0.48 |

**Table A12: Estimated CFs for Rural Two Way Two Lane Intersections Region 4 without CMFs**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 59 | 15 | 36 | 21 | 35 | 12 | 34 | 19 | 33 | 19 | 34 | 0.41 | 0.60 | 0.35 | 0.57 | 0.56 | 0.50 |
| 4-leg, minor STOP | 65 | 63 | 78 | 62 | 78 | 50 | 78 | 43 | 75 | 47 | 75 | 0.81 | 0.79 | 0.64 | 0.57 | 0.63 | 0.69 |
| 4-leg, signalized | | | | | | | | | | | | | | | | | |

# APPENDIX B: RURAL MULTILANE INTERSECTIONS DATA

**Table B1: Summary of the results for Tennessee Rural Multilane Intersections Calibration Factors—With CMFs**

| Rural Multilane Intersections | **A:** Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model |
|---|---|---|
| Unsignalized three-leg (stop control on minor-road approaches) (3ST) | 2.201 | 2.202 |
| Unsignalized four-leg (stop control on minor-road approaches) (4ST) | 1.959* | 2.144* |
| Signalized four-leg (4SG) | ISD | ISD |
| | ISD= Insufficient Sample Size Data | |

**Table B2: Summary of the results for Tennessee Rural Multilane Intersections Calibration Factors—NoCMFs**

| Rural Multilane Intersections | **A:** Five Years (2011-2015) Average | **B:** Using Averaged Crashes and AADTs in the Model |
|---|---|---|
| Unsignalized three-leg (stop control on minor-road approaches) (3ST) | 1.215 | 1.216 |
| Unsignalized four-leg (stop control on minor-road approaches) (4ST) | 0.902 | 0.988 |
| Signalized four-leg (4SG) | 0.526 | 0.525 |

**Table B3: Estimated CFs for Rural Multilane Intersections statewide with CMF**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 36 | 81 | 32 | 62 | 29 | 74 | 31 | 61 | 31 | 64 | 31 | 2.57 | 2.08 | 2.40 | 1.94 | 2.02 | 2.20 |
| 4-leg, minor STOP | 12 | 66 | 25 | 60 | 25 | 59 | 24 | 30 | 24 | 61 | 26 | 2.61 | 2.43 | 2.44 | 1.26 | 1.05 | 1.96 |
| 4-leg, signalized | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |

**Table B4: Estimated CFs for Rural Multilane Intersections statewide without CMFs**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 36 | 81 | 57 | 62 | 54 | 74 | 56 | 61 | 57 | 64 | 57 | 0.54 | 0.61 | 0.49 | 0.47 | 0.45 | 0.51 |
| 4-leg, minor STOP | 12 | 66 | 55 | 60 | 53 | 59 | 53 | 30 | 52 | 61 | 57 | 0.86 | 0.88 | 0.72 | 0.71 | 0.56 | 0.75 |
| 4-leg, signalized | 158 | 952 | 1719 | 949 | 1713 | 879 | 1705 | 904 | 1710 | 858 | 1785 | 0.55 | 0.55 | 0.52 | 0.53 | 0.48 | 0.53 |

**Table B5: Estimated CFs for Rural Multilane Intersections Region 1 without CMFs**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 12 | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD |
| 4-leg, minor STOP | 2 | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD |
| 4-leg, signalized | 37 | 209 | 355 | 161 | 351 | 174 | 338 | 162 | 345 | 168 | 358 | 0.59 | 0.46 | 0.52 | 0.47 | 0.47 | 0.50 |

**Table B6: Estimated CFs for Rural Multilane Intersections Region 2 without CMFs**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 6 | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD |
| 4-leg, minor STOP | 0 | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD |
| 4-leg, signalized | 33 | 103 | 212 | 113 | 209 | 101 | 205 | 106 | 204 | 98 | 210 | 0.49 | 0.54 | 0.49 | 0.52 | 0.47 | 0.50 |

**Table B7: Estimated CFs for Rural Multilane Intersections Region 3 without CMFs**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 6 | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD |
| 4-leg, minor STOP | 2 | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD |
| 4-leg, signalized | 45 | 385 | 634 | 407 | 636 | 351 | 637 | 365 | 647 | 365 | 684 | 0.61 | 0.64 | 0.55 | 0.56 | 0.53 | 0.58 |

**Table B8: Estimated CFs for Rural Multilane Intersections Region 4 without CMFs**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 12 | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD |
| 4-leg, minor STOP | 8 | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD | ISD |
| 4-leg, signalized | 43 | 255 | 519 | 268 | 518 | 253 | 525 | 271 | 514 | 227 | 535 | 0.57 | 0.52 | 0.48 | 0.53 | 0.42 | 0.49 |

# APPENDIX C: URBAN AND SUBERBAN INTERSECTIONS DATA

**Table C1: Summary of the results for Tennessee Urban and suburban arterials (Multiple-vehicles collisions) Intersections Calibration Factors-With CMFs**

| **Intersections** | **Tennessee Calibration Factors (with CMFs)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Statewide** | | **Region 1** | | **Region 2** | | **Region 3** | | **Region 4** | |
| | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model |
| Unsignalized three-leg (stop control) (3ST) | 2.000 | 1.998 | 1.847 | 1.848 | 1.753 | 1.748 | 3.990 | 3.974 | 1.720 | 1.720 |
| Unsignalized four-leg (stop control) (4ST) | 1.834 | 1.830 | 2.164 | 2.159 | 1.989 | 1.986 | 1.583 | 1.580 | 1.750 | 1.745 |
| Signalized three-leg (3SG) | 2.505 | 2.499 | 2.386 | 2.375 | 2.052 | 2.047 | 2.825 | 2.823 | 2.731 | 2.725 |
| Signalized four-leg (4SG) | 2.622 | 2.617 | 2.366 | 2.363 | 2.372 | 2.369 | 2.635 | 2.625 | 2.941 | 2.937 |

**Table C2: Summary of the results for Tennessee Urban and suburban arterials (Multiple-vehicles collisions Calibration Factors—No CMFs**

| Intersections | Tennessee Calibration Factors (without CMFs) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Statewide | | Region 1 | | Region 2 | | Region 3 | | Region 4 | |
| | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model |
| Unsignalized three-leg (stop control) (3ST) | 1.820 | 1.818 | 1.847 | 1.848 | 1.753 | 1.748 | 2.856 | 3.616 | 1.564 | 1.565 |
| Unsignalized four-leg (stop control) (4ST) | 1.668 | 1.665 | 1.970 | 1.965 | 1.810 | 1.807 | 1.441 | 1.438 | 1.592 | 1.588 |
| Signalized three-leg (3SG) | 1.790 | 1.780 | 1.699 | 1.691 | 1.462 | 1.458 | 2.012 | 2.010 | 1.945 | 1.941 |
| Signalized four-leg (4SG) | 1.780 | 1.775 | 1.605 | 1.603 | 1.609 | 1.606 | 1.787 | 1.780 | 1.994 | 1.992 |

**Table C3: Summary of the results for Tennessee Urban and suburban arterials (Single-vehicles collisions) Intersections Calibration Factors - With CMFs**

| Intersections | Tennessee Calibration Factors (with CMFs) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Statewide | | Region 1 | | Region 2 | | Region 3 | | Region 4 | |
| | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model |
| Unsignalized three-leg (stop control) (3ST) | 0.819 | 0.818 | 0.574 | 0.574 | 0.419 | 0.418 | 0.930 | 0.931 | 1.294 | 1.292 |
| Unsignalized four-leg (stop control) (4ST) | 0.982 | 0.980 | 0.940 | 0.938 | 0.822 | 0.820 | 0.845 | 0.844 | 1.180 | 1.178 |
| Signalized three-leg (3SG) | 1.805 | 1.803 | 1.091 | 1.085 | 1.684 | 1.681 | 2.551 | 2.556 | 2.118 | 2.115 |
| Signalized four-leg (4SG) | 1.652 | 1.645 | 1.249 | 1.247 | 1.861 | 1.855 | 1.504 | 1.493 | 2.007 | 1.996 |

**Table C4: Summary of the results for Tennessee Urban and suburban arterials (Single-vehicles collisions) Intersections Calibration Factors — No CMFs**

| Intersections | Tennessee Calibration Factors (without CMFs) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Statewide | | Region 1 | | Region 2 | | Region 3 | | Region 4 | |
| | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model | Five Years (2011-2015) Average | Using Averaged AADTs in the Model |
| Unsignalized three-leg (stop control) (3ST) | 0.746 | 0.745 | 0.522 | 0.522 | 0.381 | 0.380 | 0.733 | 0.848 | 1.175 | 1.176 |
| Unsignalized four-leg (stop control) (4ST) | 0.893 | 0.892 | 0.856 | 0.854 | 0.748 | 0.746 | 0.769 | 0.768 | 1.074 | 1.072 |
| Signalized three-leg (3SG) | 1.289 | 1.284 | 0.777 | 0.773 | 1.199 | 1.197 | 1.817 | 1.820 | 1.508 | 1.506 |
| Signalized four-leg (4SG) | 1.121 | 1.115 | 0.847 | 0.845 | 1.262 | 1.258 | 1.020 | 1.012 | 1.361 | 1.354 |

**Table C5: Estimated CFs for Urban and Suburban arterials (Multiple vehicle collisions) Intersections Statewide with CMFs**

| Facility Type | n | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| | | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 156 | 198 | 101 | 221 | 100 | 196 | 102 | 201 | 102 | 205 | 105 | 1.97 | 2.20 | 1.92 | 1.96 | 1.95 | 2.00 |
| 4-leg, minor STOP | 138 | 365 | 165 | 316 | 164 | 325 | 165 | 273 | 164 | 237 | 170 | 2.22 | 1.92 | 1.98 | 1.67 | 1.39 | 1.83 |
| 3-leg signalized | 131 | 762 | 263 | 689 | 267 | 684 | 278 | 635 | 276 | 650 | 285 | 2.90 | 2.58 | 2.46 | 2.30 | 2.28 | 2.51 |
| 4-leg signalized | 165 | 1505 | 523 | 1543 | 525 | 1429 | 542 | 1285 | 531 | 1241 | 554 | 2.88 | 2.94 | 2.64 | 2.42 | 2.24 | 2.62 |

**Table C6: Estimated CFs for Urban and Suburban arterials (Multiple vehicle collisions) Intersections Statewide without CMFs**

| | | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| Facility Type | n | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 156 | 198 | 111 | 221 | 110 | 196 | 112 | 201 | 113 | 205 | 116 | 1.79 | 2.00 | 1.75 | 1.78 | 1.77 | 1.82 |
| 4-leg, minor STOP | 138 | 365 | 181 | 316 | 181 | 325 | 181 | 273 | 180 | 237 | 187 | 2.02 | 1.75 | 1.80 | 1.52 | 1.27 | 1.67 |
| 3-leg signalized | 131 | 762 | 369 | 689 | 375 | 684 | 390 | 635 | 387 | 650 | 400 | 2.06 | 1.84 | 1.76 | 1.64 | 1.62 | 1.78 |
| 4-leg signalized | 165 | 1505 | 771 | 1543 | 774 | 1429 | 799 | 1285 | 784 | 1241 | 817 | 1.95 | 1.99 | 1.79 | 1.64 | 1.52 | 1.78 |

**Table C7: Estimated CFs for Urban and Suburban arterials (Single-vehicle collisions) Intersections Statewide with CMFs**

| | | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| Facility Type | n | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 156 | 22 | 30 | 26 | 30 | 26 | 30 | 28 | 30 | 22 | 30 | 0.73 | 0.86 | 0.86 | 0.93 | 0.73 | 0.82 |
| 4-leg, minor STOP | 138 | 30 | 25 | 30 | 25 | 29 | 25 | 18 | 25 | 18 | 26 | 1.18 | 1.18 | 1.14 | 0.71 | 0.70 | 0.98 |
| 3-leg signalized | 131 | 33 | 21 | 46 | 21 | 39 | 22 | 43 | 22 | 33 | 22 | 1.57 | 2.17 | 1.81 | 1.99 | 1.49 | 1.81 |
| 4-leg signalized | 165 | 72 | 34 | 68 | 34 | 47 | 34 | 58 | 34 | 36 | 35 | 2.14 | 2.02 | 1.37 | 1.71 | 1.03 | 1.65 |

**Table C8: Estimated CFs for Urban and Suburban arterials (Single -vehicle collisions) Intersections Statewide without CMFs**

| | | Observed crashes (O) and Predicted Crashes (P) | | | | | | | | | | Calibration Factor (CF) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2011 | 2012 | 2013 | 2014 | 2015 | 2011-2015 |
| Facility Type | n | O | P | O | P | O | P | O | P | O | P | CF | CF | CF | CF | CF | CF |
| 3-leg, minor STOP | 156 | 22 | 33 | 26 | 33 | 26 | 33 | 28 | 33 | 22 | 33 | 0.66 | 0.78 | 0.78 | 0.84 | 0.66 | 0.75 |
| 4-leg, minor STOP | 138 | 30 | 28 | 30 | 28 | 29 | 28 | 18 | 28 | 18 | 28 | 1.07 | 1.07 | 1.04 | 0.65 | 0.64 | 0.89 |
| 3-leg signalized | 131 | 33 | 29 | 46 | 30 | 39 | 30 | 43 | 30 | 33 | 31 | 1.12 | 1.54 | 1.29 | 1.42 | 1.06 | 1.29 |
| 4-leg signalized | 165 | 72 | 50 | 68 | 50 | 47 | 51 | 58 | 50 | 36 | 52 | 1.45 | 1.37 | 0.93 | 1.16 | 0.70 | 1.12 |

***Note: n= number of intersections***